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Description

The invention relates to an apparatus for producing and/or receiving a sector-scanned beam of ultrasound energy that is suitable to be directed through a space between obstacles to scan a region behind the obstacles, the apparatus comprising:

— an array, including a plurality of ultrasound transducer elements disposed along a substantially circularly curved line, each element being oriented to direct ultrasound energy towards and to receive ultrasound energy from the center of the curve, and

— means for transmitting electrical pulses to and for receiving electrical pulses from the transducer elements,

— means for connecting a group of active transducer elements to the means for transmitting electrical pulses and for receiving electrical pulses, the group of active elements comprising a preselected number of adjacent transducer elements in the array said preselected number being greater than one and less than the total number of transducer elements in the array,

— means for sequentially changing the elements in the active group to incrementally shift the active group along the curve.

Internal body organs may be imaged and otherwise characterized by apparatus which directs pulses of ultrasound energy into the body and subsequently detects echos which originate when the energy is reflected from tissue interfaces or other discontinuities within the body. In typical apparatus the ultrasound energy is directed into the body in a relatively narrow beam. Electric signals which describe the position and direction of the beam with respect to the body, as well as the relative arrival time and amplitude of the echos, are utilized to generate a visual display and/or mapping of the internal body structures. In many applications the direction of the ultrasound beam is manually controlled by a technician (generally by physical motion of a probe head) to build up a display pattern. While these methods are adequate for imaging stationary body structures, the time required for physical motion of a probe is generally much too long to image rapidly moving body structures (for example the valves in a beating heart) in real time. Ultrasound systems for generating real time displays of rapidly moving body organs generally utilize electromechanical or electronic means to change the position and direction of one or more beams of ultrasound energy with respect to the body.

Motion of a beam of ultrasound energy with respect to the body may be provided by sequentially activating transducer elements in a flat linear array to effectively scan an area of the body with a sequence of substantially parallel ultrasound beams. A device of this type is described in US—A—3,013,170. A beam of ultrasound energy may, alternately, be scanned around a single origin point to produce a so-called "sector-scan". Sector-scan geometries are particularly useful since ultrasound energy may be directed between the ribs to scan the interior of the chest cavity. Sector scanning has been achieved in the prior art by rapidly rotating one or more transducers about an axis, by steering energy from a fixed transducer with a rotating ultrasound reflector, or by sequencing individual transducer elements in a linear curved array. DE—A—2,818,915 describes a curved transducer array with individual transducers which are individually activated to produce a sector-scan.

The transverse spatial resolution which may be obtained from a sequence array of ultrasound transducers is related to dimensions of the individual transducer elements in the array. Small transducer elements are desirable for obtaining fine resolution. The amount of ultrasound energy produced by an individual transducer element is, however, limited by its size. The signal-to-noise ratio of the returned ultrasound echos necessarily depends on the amount of ultrasound energy introduced into the body. Thus, the signal to noise ratio suffers if small transducer elements are individually activated to achieve a scanning action. Diffraction effects will furthermore, cause spreading of an ultrasound beam which originates from a single, small ultrasound transducer element. In the apparatus described in DE—A—2,818,915 the ultrasonic beam is directed through a small window in order to decrease its lateral dimensions, thereby decreasing the amount of energy in the beam even further.

In the prior art the amount of energy in a beam produced by a flat linear array has been increased by simultaneously activating a group of adjacent transducers. Means were provided for incrementally shifting the active group along the array to provide fine spatial resolution and high signal-to-noise ratios. While this technique is appropriate for use with flat transducer arrays, which produce a parallel beam scanning geometry, the simultaneous activation of a group of adjacent transducers in a curved array inherently generates a focussed ultrasound beam.

An apparatus of the kind referred to in the opening paragraph is disclosed in DE—A—26.54.280. This apparatus comprises a sequenced group curved array of transducers in which the focus is slightly displaced to a point at a distance from the array of about 1 2/3 times the natural focual distance. This displacement of the focus is obtained by activating the outer transducers of the group with a signal having a 90° phase shift relative to the signal activating the transducers located near the center of the group. In this manner an acceptable resolution is obtained only in a very limited area around the new focus.

It is an object of the invention to provide an apparatus of the kind described in which simultaneous activation of a group of adjacent transducers is possible without a focussed ultrasound beam being generated. To this end the apparatus according to the invention is characterized in that it further comprises:

— means for defocussing ultrasound energy produced and received by the transducer elements in the active group which means function to cause said ultrasound energy to be directed in a substantially parallel beam,

— the means for defocussing comprising means for delaying the electrical pulses which are transmitted to and received from elements in the active group, pulses from each element being delayed in proportion to the distance between that element and the center of the active group,

— the means for connecting an active group comprising a matrix of switches, and the means for sequentially changing elements in the active group comprising a read only memory having outputs connected to actuate the switches and a sequencer circuit connected to sequentially address the read only memory.

The invention also relates to a method for manufacturing a curved array of ultrasound transducer elements for such an apparatus, comprising the steps of:

attaching front and rear conductive electrodes to front and rear surfaces respectively of a substantially flat bar of piezo-electric ceramic;

cutting a plurality of parallel grooves through the rear electrode and partially through the thickness of the bar;

placing the front surface of the grooved bar on a semicylindrical mandrel, the grooves being parallel to the axis of the mandrel, and bending the bar around the mandrel so that portions of the bar under the grooves are fractured to separate individual transducer elements, the front electrode remaining intact during the fracturing of the bar, the individual elements being retained against the mandrel by at least the front electrode; and

filling the spaces between the individual transducer elements with a resin binder which retains the elements on an arc conforming to the surface of the mandrel.

It is pointed out that GB—A—1,437,486 describes a curved transducer array comprising straight linear arrays that consist of slabs of piezo-electric material that have been provided with slots.

The invention will now be explained more in detail with reference to the attached drawings in which:

Figures 1 and 2 show a prior art sequenced flat array of ultrasound transducers;

Figure 3 is a curved transducer array of the present invention;

Figure 4 illustrates the principle of time delay defocussing for the array of Fig. 3;

Figure 5 schematically illustrates a system for operating the array of Figure 3;

Figure 6 is an alternate embodiment of the invention which includes a defocussing lens;

Figure 7 illustrates a stage in the production of the array of Figure 3;

Figure 8 illustrates a completed array; and

Figure 9 is a detail of Figure 8.

Description of the Preferred Embodiments

Figure 1 is a linear array of ultrasound transducers 110 which is known in the prior art. A series of individual transducers elements 100 are disposed along a line 101. Separate electrodes 102 are provided for each transducer in the array and are connected to electronic circuits (not shown) which permit sequential activation of the elements to, in effect, move the source of an ultrasound beam along the line 101.

Figure 2 illustrates an application of the array 110 of Figure 1. A group of adjacent transducers 111 are simultaneously activated to produce a beam of ultrasound energy 112 which is inwardly projected into a body 113. The array 110 is disposed on the surface of a probe assembly 114 which includes switching circuits 115. The switching circuits act to incrementally shift the group of active transducers 111 along the array to generate a linear scan of the beam 112 with respect to the body. The operation of prior art imaging systems with incrementally shifted arrays is described in the articles *Ultrasonic Imaging Using Arrays,* Albert Macovski and *Methods and Terminology for Diagnostic Ultrasound Imaging Systems,* Maxwell G. Maginness in the Proceedings of the IEEE, Vol. 67, No. 4, April 1979 at page 484 and 641 respectively. Those articles are incorporated herein, by reference, as background material. As indicated in those articles, the incremental shifting of a group of transducers within the array improves spatial resolution and provides a higher signal to noise ratio than could be achieved by the sequential activation of individual transducer elements.

British patent Specification 1,546,445 describes a curved linear array of transducers which are individually activated to generate a sector-scanned ultrasound beam. A positive (converging) lens is utilized with the transducer array to focus the beam through the spaces between the ribs. Because only one transducer element is active at a time, the array of British patent 1,546,445 suffers from relatively low spatial resolution and signal-to-noise ratio. The performance of the array cannot, however, be improved by directly applying the incrementally shifted active group geometry of Figure 2 to the curved array configuration. The simultaneous activation of a group of adjacent elements on a curved array necessarily produces a sharply focussed beam which diverges in the far field and is unsuitable for medical imaging.

Figure 3 schematically illustrates a transducer array of the present invention. A plurality of electro-acoustic transducer elements 200 are disposed along an arc and are oriented to project and receive ultrasound energy in the direction of the center of the arc. The individual elements 200 in the array are provided with separate electrodes and are connected via wires 202, and a sequencing circuit to pulse generator and receiver circuits (not shown). The array is contained in a housing 204 which includes an ultrasound transmissive window 206. The housing may be filled with an ultrasound transmissive fluid 208, for example, castor oil, which is matched to the ultrasound transmissive properties of the human body. Alternately the housing may be filled with a solid material. In general the filling should have an acoustic attenuation between those of water and human tissue and should have an acoustic impedance which is matched to the impedance of human tissue.

A group of adjacent transducer elements (for example 220) within the array is activated for the transmission and reception of each ultrasound pulse. The active group of transducers is incrementally shifted along the array, one transducer at a time, on a pulse to pulse basis to provide a sector scan of ultrasound energy. Defocussing means are included to compensate for the strong inherent focussing of the curved array. The curved array, with an incrementally shifted group of active detectors, in combination with the defocussing means, produces a finer spatial resolution and higher signal to noise ratio than curved sequenced arrays of the prior art.

Figure 4 illustrates a preferred embodiment of the defocussing means. At a given instant, a group 220 of adjacent transducers A-K within the array is activated by sequencing switches (not shown for the sake for clarity). The central transducer F within the zone is connected directly to ultrasound pulse generator 240 and receiver 250 circuits via a transmit-receive (TR) switch 260. The transducer pair E and G immediately adjacent the central transducer is connected to the TR switch 260 via a first delay 270. The next adjacent pair of transducers D and H are connected to the TR switch through a second delay circuit 280 which provides a longer delay than the delay circuit 270. Each next adjacent pair of transducers within the group (i.e. C and I, B and J, A and K) are connected to the TR switch via delay circuits (290, 300, 310) which provide increasing delays in proportion to the distance from the center of the active group to the associated transducers. The magnitude of the delays are chosen, using techniques which are well known in the art and which are described, for example, in the above referenced Macovski article, to compensate for the physical focussing effects of the curved array and thus provide a more parallel beam of ultrasound energy. Alternately the beam may thus be focussed at a point deep within the body of a patient.

Figure 5 illustrates a system for incrementally shifting the active group along the transducer array. Pulsers 400, receiver amplifiers 410, and associated TR isolators 420 are connected in a conventional fashion to first ends of a bank of bidirectional delay lines 430. The bank of delay lines 430 includes delay lines of varying time delay which are calculated to provide the defocussing compensation for the active group as described above with respect to the Figure 4. The opposite end of each delay line in the bank 430 is connected to a row of switches in an analog switch matrix 440. Each column of switches in the switch matrix 440 is connected to a separate element 200 in the transducer array 450. A separate switch (which may be a MOS transistor) is provided at each cross point (that is the intersection of each row with each column) in the switch matrix. The switching elements are individually activated by the output lines of a read-only memory (ROM) 460. Input lines of the read-only memory 460 are addressed by the output of a sequencer circuit which may be a sequential counter 470 driven by a clock 480. The sequencer circuit addresses consecutive words in the read-only memory which establish the connection patterns between the individual transducer elements in the array and corresponding delay lines to effect incremental shifting of a defocussed, active group along the array. As an example, Table I illustrates the first three words of a read-only memory which shifts an active group of nine transducer elements along an array by establishing connections to four delay lines I through IV.

TABLE I

Delay Line	1	2	3	4	5	6	7	8	9	10	11	12	13	
I	0	0	0	1	0	0	0	0	0	0	0	0	0	
II	0	0	1	0	1	0	0	0	0	0	0	0	0	WORD 1
III	0	1	0	0	0	1	0	0	0	0	0	0	0	
IV	1	0	0	0	0	0	1	0	0	0	0	0	0	
I	0	0	0	0	1	0	0	0	0	0	0	0	0	
II	0	0	0	1	0	1	0	0	0	0	0	0	0	WORD 2
III	0	0	1	0	0	0	1	0	0	0	0	0	0	
IV	0	1	0	0	0	0	0	1	0	0	0	0	0	
I	0	0	0	0	0	1	0	0	0	0	0	0	0	
II	0	0	0	0	1	0	1	0	0	0	0	0	0	WORD 3
III	0	0	0	1	0	0	0	1	0	0	0	0	0	
IV	0	0	1	0	0	0	0	0	1	0	0	0	0	

The bit patterns of Table I are shortened for the sake of clarity of illustration; the principles illustrated therein may be extended to active groups and arrays which include larger or smaller numbers of transducer elements.

Figure 6 is an alternate embodiment of a transducer array wherein the defocussing means comprise a negative lens 500. A group of transducers is sequentially shifted across the array as in the embodiment of Figure 3 to produce a sector scan. All of the transducers in the group 200 may be simultaneously pulsed. Alternately, the delay line defocussing means of Figure 4 may be utilized in conjunction with the lens 500. The lens may be constructed from metal or plastic and may advantageously comprise two negative lens elements separated by a fluid-filled cavity 510.

Figure 7 illustrates first steps in a preferred method for manufacturing the transducer array. The array is advantageously formed from a single rectangular bar 600 of piezo-electric ceramic (which may comprise Type PZT-5). Copper electrodes 605 and 610 are bonded to the front 601 and rear 602 major surfaces of the bar with a silver bearing epoxy resin. A flexible matching window 615 is then cast directly on the front electrode. The matching window may be advantageously cast from a mixture of two parts of a Stycast 1264 resin binder and one part tungsten powder. The window is cast by pouring the mixture directly onto the surface of the front electrode and allowing the tungsten powder to settle. After the resin is cured, the window is machined to a thickness of one quarter acoustic wavelength at the operating frequency of the array. For example, a window designed for operation at 3.5 MHz is machined to approximately 0.09 mm thickness.

A series of parallel grooves 620 are then cut through the rear electrode 610 and into the upper surface of the bar to segregate individual transducer elements 630 with their associated rear electrodes. Typically the grooves are approximately 0.13 mm wide and penetrate to 75% of the thickness of the ceramic bar.

In a preferred embodiment of the array the ceramic bar is approximately 80.5 millimeters long, 12.5 millimeters wide, and 2.0 millimeters thick. The bar is divided by 71 saw cuts to form 72 transducer elements. The rear electrodes on the endmost transducer elements are grounded to the front electrode so that the array comprises 70 functional transducer elements.

Figures 8 and 9 illustrate the further construction of the array. The grooved ceramic bar 600 with attached electrodes 605 and 610 and window 615 is formed around a semi-cylindrical mandrel 650, the grooves in the bar being parallel to the axis of the cylinder. As illustrated in detail Figure 9 the bar cracks under each groove 620 to produce a curved array of separate, electroded transducer elements 630 which are retained in place by the front electrode 605 and window 615.

A supporting foam air cell 660 is then cast between the elements 630 and around the rear surface of the curved transducer array. The air cell retains the transducer elements in place and further provides a low acoustic impedance backing for the individual elements. The air cell may typically comprise glass micro-balloons in an epoxy resin binder.

In a preferred embodiment of the invention the upper electrodes 610 are wider than the ceramic bar and are folded back along the edges of the air cell to provide electrical connections to the individual elements.

Claims

1. Apparatus for producing and/or receiving a sector-scanned beam of ultrasound energy that is suitable to be directed through a space between obstacles to scan a region behind the obstacles, the apparatus comprising:

— an array, including a plurality of ultrasound transducer elements (200) disposed along a substantially circularly curved line, each element being oriented to direct ultrasound energy towards and to receive ultrasound energy from the center of the curve, and

— means for transmitting (240) electrical pulses to and for receiving (250) electrical pulses from the transducer elements,

— means (440) for connecting a group (220) of active transducer elements (200) to the means for transmitting (240) electrical pulses and for receiving (250) electrical pulses, the group of active elements comprising a preselected number of adjacent transducer elements in the array, said preselected number being greater than one and less than the total number of transducer elements in the array,

— means (460, 470) for sequentially changing the elements in the active group to incrementally shift the active group along the curve, characterized in that the apparatus further comprises:

— means (430, 500) for defocussing ultrasound energy produced and received by the transducer elements in the active group which means function to cause said ultrasound energy to be directed in a substantially parallel beam,

— the means for defocussing comprising means (430) for delaying the electrical pulses which are transmitted to and received from elements (200) in the active group (220), pulses from each element being delayed in proportion to the distance between that element and the center of the active group,

— the means for connecting an active group comprising a matrix (440) of switches, and the means for sequentially changing elements in the active group comprising a read only memory (460) having outputs connected to actuate the switches and a sequencer circuit (470) connected to sequentially address the read only memory.

2. Apparatus as claimed in Claim 1, characterized in that the means for defocussing comprise a negative lens (500) disposed in the path of ultrasound energy projected from the elements (200) of the active group (220).

3. Apparatus as claimed in any one of the preceding Claims, characterized in that each element (630) includes a front face directed away from the center of the curve and further comprising:

— front (605) and back (610) conductive electrodes disposed, respectively, on the front and back faces of the elements.

4. Apparatus as claimed in Claim 3, characterized in that a single continuous electrode (605) is disposed across the front faces of all elements (630) in the array.

5. Apparatus as claimed in Claim 3, characterized in that it further comprises a matching window (615) disposed adjacent the front surface of the transducer elements (630), the front electrode (605) being disposed between the matching window and the transducer elements.

6. Apparatus as claimed in Claim 3, characterized in that it further comprises an air cell (660) disposed over the rear electrodes (610) of the transducer elements (630).

7. Apparatus as claimed in Claim 6, characterized in that the air cell comprises glass microballoons in a resin binder.

8. A method for manufacturing a curved array of ultrasound transducer elements (630) for an apparatus as claimed in any one of the preceding Claims, characterized in that it comprises the steps of:

— attaching front (605) and rear (610) conductive electrodes to front and rear surfaces respectively of a substantially flat bar (600) of piezo-electric ceramic,

— cutting a plurality of parallel grooves (620) through the rear electrode and partially through the thickness of the bar,

— placing the front surface of the grooved bar on a semicylindrical mandrel (650), the grooves being parallel to the axis of the mandrel, and bending the bar around the mandrel so that portions of the bar under the grooves are fractured to separate individual transducer elements, the front electrode remaining intact during the fracturing of the bar, the individual elements being retained against the mandrel by at least the front electrodes, and

— filling the spaces between the individual transducer elements with a resin binder (660) which retains the elements on an arc conforming to the surface of the mandrel.

Patentansprüche

1. Gerät zum Erzeugen und/oder Empfangen eines sektorweise abgetasteten Ultraschallenergiestrahls,

der sich zum Richten durch einen Raum zwischen Hindernissen für die Abtastung eines Gebiets hinter den Hindernissen eignet, welches Gerät folgende Elemente enthält:

— eine Anordnung mit einer Anzahl von Ultraschallwandlerelementen (200), die entlang einer im wesentlichen kreisförmig gekrümmten Linie angeordnet sind, wobei jedes Element zum Richten von Ultraschallenergie auf die Kurvenmitte und zum Empfangen von Ultraschallenergie aus der Kurvenmitte orientiert ist, und

— Mittel (240) zum Übertragen elektrischer Impulse auf die Wandlerelemente und Mittel (250) zum Empfangen elektrischer Impulse aus den Wandlerelementen,

— Mittel (440) zum Anschließen einer Gruppe (220) aktiver Wandlerelemente (200) an die Mittel (240) zum Übertragen elektrischer Impulse und an die Mittel (250) zum Empfangen elektrischer Impulse, wobei die Gruppe aktiver Elemente eine vorgewählte Anzahl benachbarter Wandlerelemente in der Anordnung enthält, und diese vorgewählte Anzahl größer als eins und kleiner als die Gesamtzahl der Wandlerelemente in der Anordnung ist,

— Mittel (460, 470) zum sequentiellen Andern der Elemente in der aktiven Gruppe zum inkrementierenden Verschieben der aktiven Gruppe längs der Kurve, dadurch gekennzeichnet, daß das Gerät außerdem Mittel (430, 500) zum Defokussieren von in den Wandlerelementen in der aktiven Gruppe erzeugter und empfangener Ultraschallenergie, enthält, welche Mittel funktionieren zum Richten der Ultraschallenergie in einem im wesentlichen parallelen Strahl, dass die Mittel zum Defokussieren Mittel (430) zum Verzögern der elektrischen Impulse, die auf Elemente (200) in der aktiven Gruppe (220) übertragen und aus diesen Elementen (200) empfangen werden, enthalten, wobei Impulse aus jedem Element im Verhältnis zum Abstand zwischen diesem Element und der Mitte der aktiven Gruppe verzögert dass die Mittel zum Anschließen einer aktiven Gruppe eine Matrix (440) von Schaltern enthalten und dass die Mittel zum sequentiellen Andern von Elementen in der aktiven Gruppe folgende Elemente enthalten: eine Festwertspeicher (460), dessen Ausgänge zum Aktivieren der Schalter angeschlossen sind und eine Sortiererschaltung (470) die zum sequentiellen Adressieren des Festwertspeichers angeschlossen ist.

2. Gerät nach Anspruch 1, dadurch gekennzeichnet, daß die Mittel zum Defokussieren eine negative Linse (500) enthalten, die im Weg der Ultraschallenergie angeordnet ist, die von den Elementen (200) der aktiven Gruppe (220) projiziert wird.

3. Gerät nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß jedes Element (630) eine der Kurvenmitte zugewandte Vorderfläche und eine von der Kurvenmitte abgewandte Rückfläche besitzt, und dass vordere (605) und hintere (610) lietende Elektroden, auf der Vorderfläche bzw. auf der Rückfläche der Elemente angeordnet sind.

4. Gerät nach Anspruch 3, dadurch gekennzeichnet, daß eine einzige durchgehende Elektrode (605) über die Vorderflächen aller Elemente (630) in der Anordnung angeordnet ist.

5. Gerät nach Anspruch 3, dadurch gekennzeichnet, daß es weiter ein Anpassungsfenster (615) enthält, das in der Nähe der Vorderfläche der Wandlerelemente (630) angeordnet ist, wobei die Vorderelektrode (605) zwischen dem Anpassungsfenster und den Wanderelementen angebracht ist.

6. Gerät nach Anspruch 3, dadurch gekennzeichnet, daß es außerdem eine Luftzelle (660) enthält, die über die Hinterelektroden (610) der Wanderelemente (630) angebracht ist.

7. Gerät nach Anspruch 6, dadurch gekennzeichnet, daß die Luftzelle Mikro-Glaskugeln in einem Kunstharz-Bindemittel enthält.

8. Verfahren zum Herstellen einer gekrümmten Anordnung von Ultraschallwandlerelementen (630) für ein Gerät nach einem oder mehreren der vorangehenden Ansprüche, dadurch gekennzeichnet, daß das Verfahren folgende Schritte umfaßt:

— Anbringen vorderer (605) und hinterer (610) leitender Elektroden auf Vorder- bzw. und Hinterflächen eines im wesentlichen flachen Stabes (600) aus piezoelektrischer Keramik,

— Schneiden einer Anzahl paralleler Rillen (620) in die Hinterelektrode und teilweise in die Dicke des Stabes,

— Anordnen der Vorderfläche des gerillten Stabes auf einem halbzylindrischen Dorn (650), wobei die Rillen parallel zur Dornachse verlaufen und der Stab derart um den Dorn gebogen wird, daß Teile des Stabes unter den Rillen zum Trennen einzelner Wandlerelemente auseinandergebrochen werden, wobei die Vorderelektrode beim Brechen des Stabes unbeschädigt bleibt, und die einzelnen Elemente wenigstens durch die Vorderelektroden auf dem Dorn festgehalten werden, und

— Füllen der verbliebenen Räume zwischen den einzelnen Wanderelementen mit einem Kunstharz-Bindemittel (660), daß die Elemente in einem Bogen entsprechend der Oberfläche des Dornes festhält.

Revendications

1. Appareil d'émission et/ou de réception d'un faisceau de balayage sectoriel d'énergie ultrasonore convenant pour être dirigé à travers un espace situé entre des obstacles pour balayer une région située derrière les obstacles, appareil comportant:

— un réseau comportant une pluralité d'éléments de transducteur (200) disposés suivant une ligne courbe sensiblement circulaire, chaque élément étant orienté de façon à diriger de l'énergie ultrasonore vers le centre de la courbe et à recevoir de l'énergie ultrasonore de celui-ci et

— des moyens de transmission (240) d'impulsions électriques vers les éléments de transducteur et de réception (250) d'impulsions électriques de ceux-ci,

— des moyens (440) pour relier en groupe (220) d'éléments de transducteur actifs (200) aux moyens de transmission (240) d'impulsions électriques et de réception (250) d'impulsions électriques, le groupe d'éléments actifs comportant un nombre présélectionné d'éléments de transducteur voisins dans le réseau, ledit nombre présélectionné étant supérieur à un et inférieur au nombre total d'éléments de transducteur dans le réseau,

— des moyens (460, 470) pour changer séquentiellement les éléments dans le groupe actif pour décaler le groupe actif de façon incrémentielle le long de la courbe, caractérisé en ce qu'il comporte en outre:

— des moyens (430, 500) de défocalisation de l'énergie ultrasonore produite et reçue par les éléments de transducteur dans le groupe actif, moyens qui fonctionnent de façon que ladite énergie ultrasonore soit dirigée dans un faisceau sensiblement parallèle,

— les moyens de défocalisation comportant des moyens (430) pour retarder les impulsions électriques transmises à des éléments (200) dans le groupe actif (220) et reçues par ceux-ci, des impulsions de chaque élément étant retardées en proportion de la distance comprise entre cet élément et le centre du groupe actif,

— les moyens pour relier un groupe actif comportant une matrice (440) de commutateurs et les moyens pour changer séquentiellement des éléments dans le groupe actif comportant une mémoire morte (460) munie de sorties connectées de façon à actionner les commutateurs et un circuit séquenceur (470) connecté de façon à adresser séquentiellement le mémoire morte.

2. Appareil selon la revendication 1, caractérisé en ce que les moyens de défocalisation comportent une lentille négative (500) disposée dans le trajet de l'énergie ultrasonore projetée par les éléments (200) du groupe actif (220).

3. Appareil selon l'une quelconque des revendications précédentes, caractérisé en ce que chaque élément (630) présente un face antérieure dirigée vers le centre de la courbe et une face postérieure située à l'opposé du centre de la courbe et comportant en outre:

— des électrodes conductrices antérieure (605) et postérieure (610) disposées respectivement sur les faces antérieure et postérieure des éléments.

4. Appareil selon la revendication 3, caractérisé en ce qu'une seule électrode continue (605) est disposée sur les faces antérieures de tous les éléments (630) du réseau.

5. Appareil selon la revendication 3, caractérisé en ce qu'il comporte en outre une fenêtre d'adaptation (615) disposée à proximité de la surface antérieure des éléments de transducteur (630), l'électrode antérieure (605) étant disposée entre la fenêtre d'adaptation et les éléments de transducteur.

6. Appareil selon la revendication 3, caractérisé en ce qu'il comporte en outre une alvéole (660) disposée sur les électrodes postérieures (610) des éléments de transducteur (630).

7. Appareil selon la revendication 6, caractérisé en ce que l'alvéole comporte des micro-ampoules de verre dans un liant de résine.

8. Procédé de fabrication d'un réseau courbe d'élements de transducteur ultrasonore (630) destiné à un appareil selon l'une quelconque des revendications précédentes, caractérisé en ce qu'il comporte les étapes consistant:

— à fixer des électrodes conductrices antiérieure (605) et postérieure (610) respectivement à des surfaces antérieure et postérieure d'une barre sensiblement plate (600) de céramique piézo-électrique,

— à pratiquer une pluralité de gorges parallèles (620) traversant l'électrode postérieure et traversant partiellement l'épaisseur de la barre,

— à placer la surface antérieure de la barre à gorges sur un mandrin hémicyclindrique (650), les gorges étant parallèles à l'axe du mandrin, et à courber la barre autour du mandrin de façon à rompre des parties de barre situées au-dessous des gorges pour séparer des éléments de tranducteur individuels, l'électrode antérieure restant intacte pendant la rupture de la barre et les éléments individuels étant retenus contre le mandrin par au moins les électrodes antérieures et

— à remplir les espaces entre les éléments de transducteur individuels d'un liant de résine (660) qui retient les éléments sur un arc épousant la surface du mandrin.

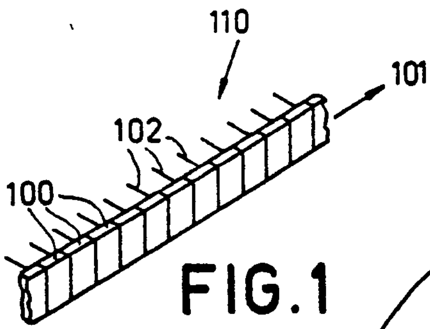

FIG.1

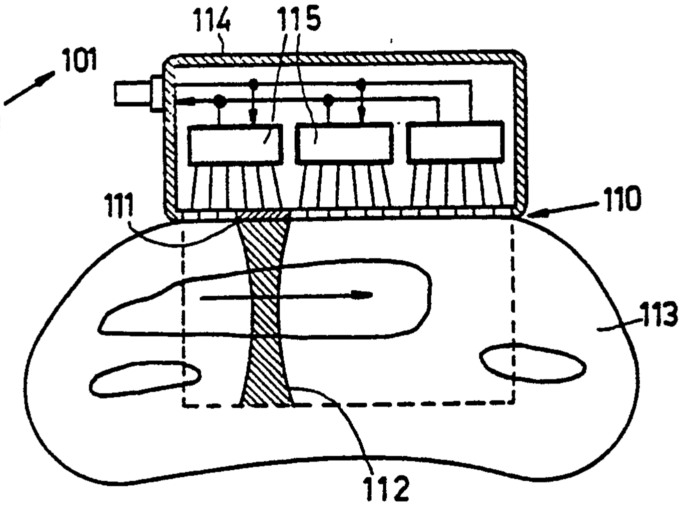

FIG.2

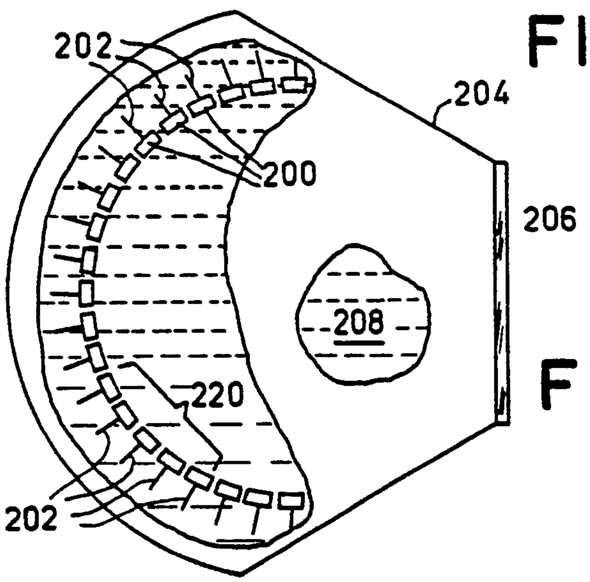

FIG.3

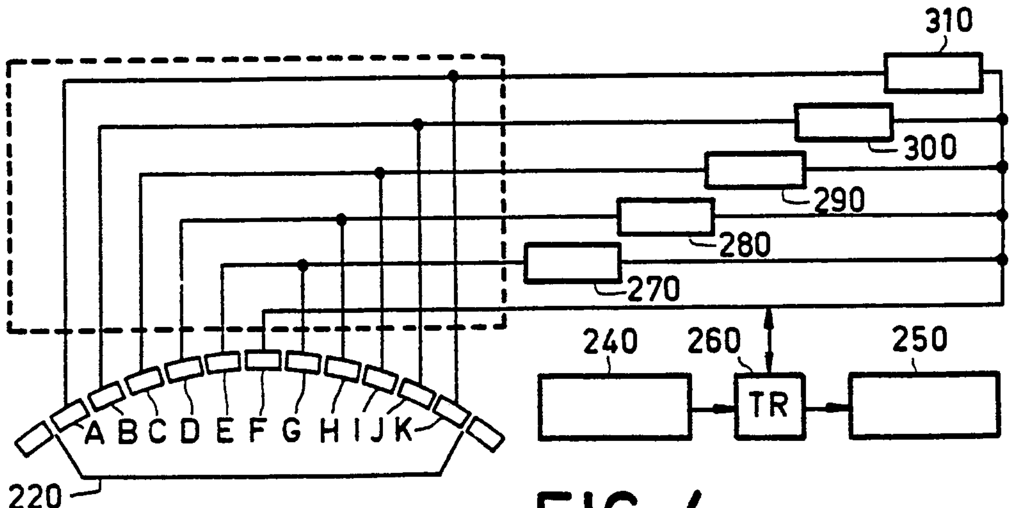

FIG. 4

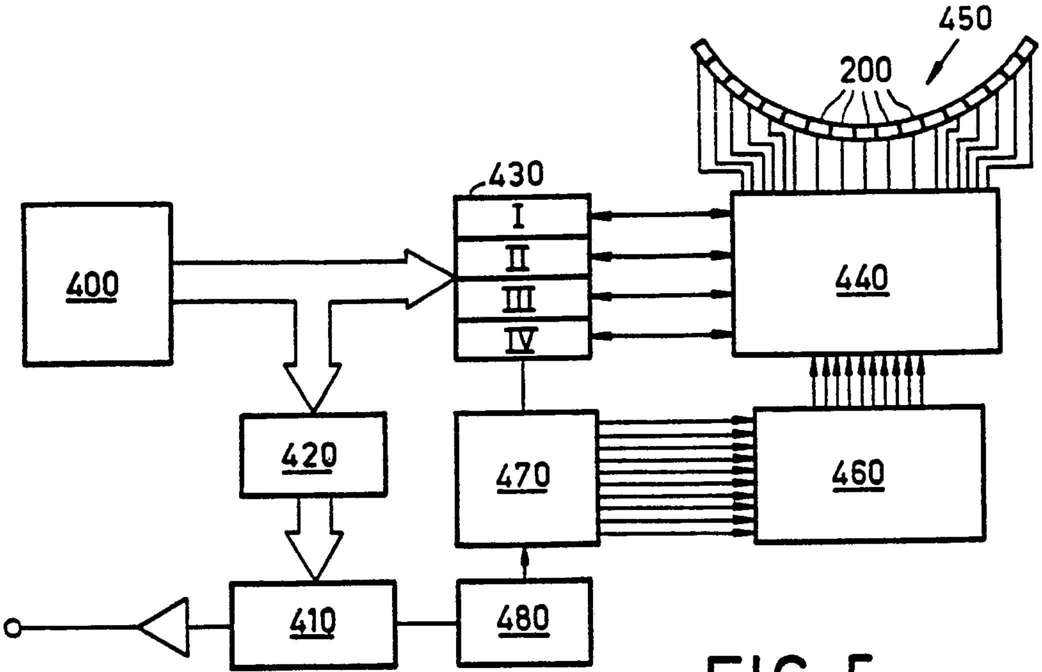

FIG. 5

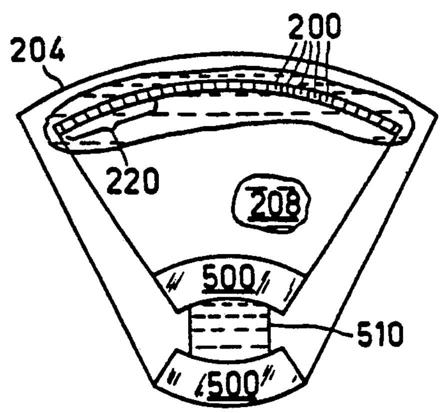

FIG. 6

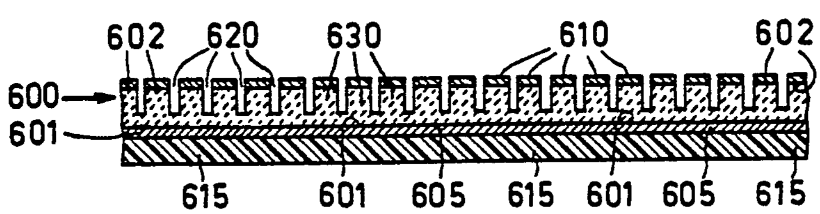

FIG. 7

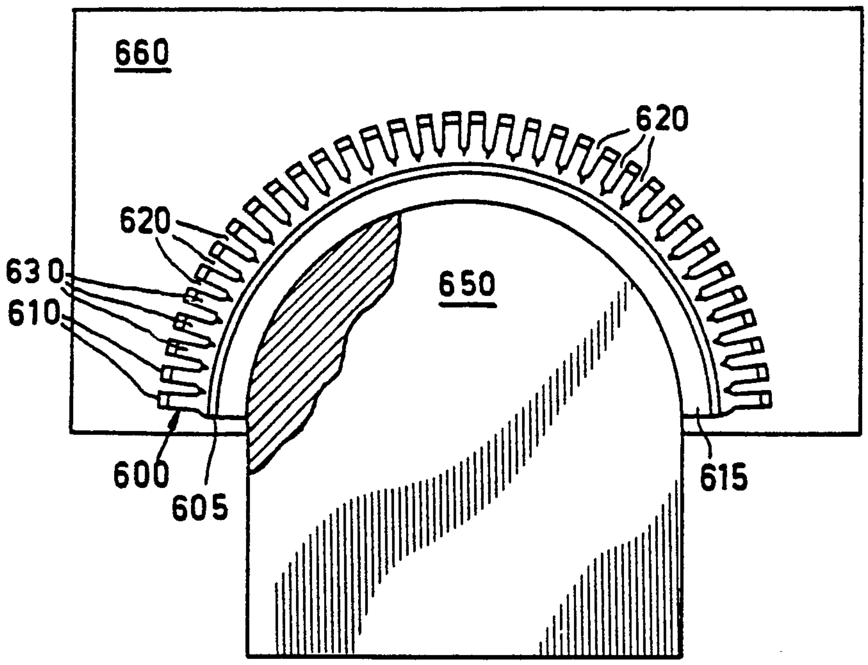
660
620
620
630
610
650
600
605
615

FIG. 8

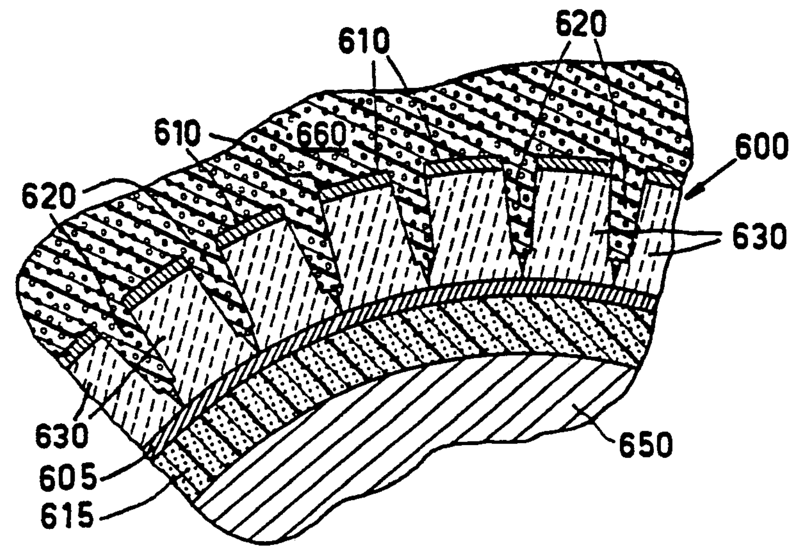
610
620
610
660
600
620
630
630
605
615
650

FIG.9