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(54) **CABLELESS COUPLING METHODS FOR ULTRASOUND**

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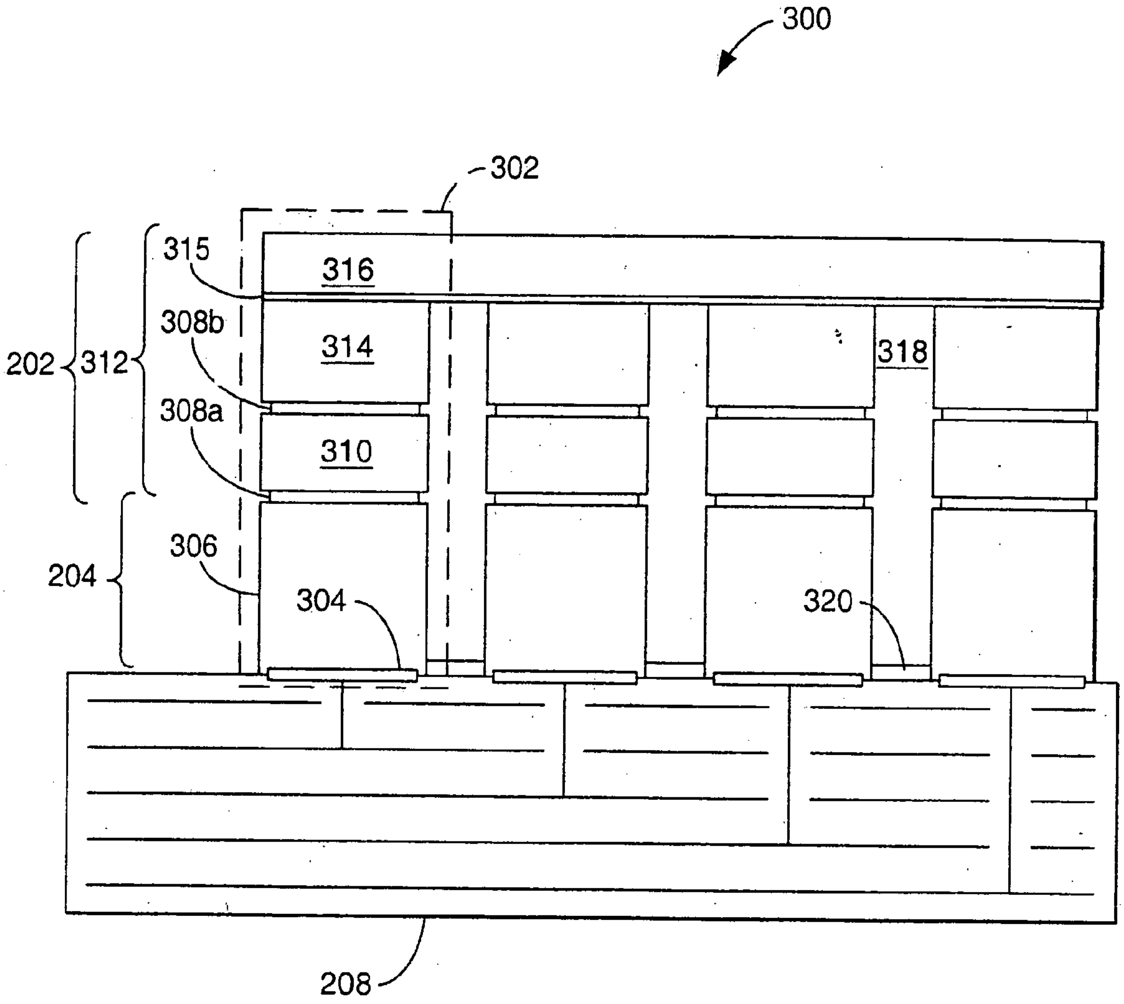
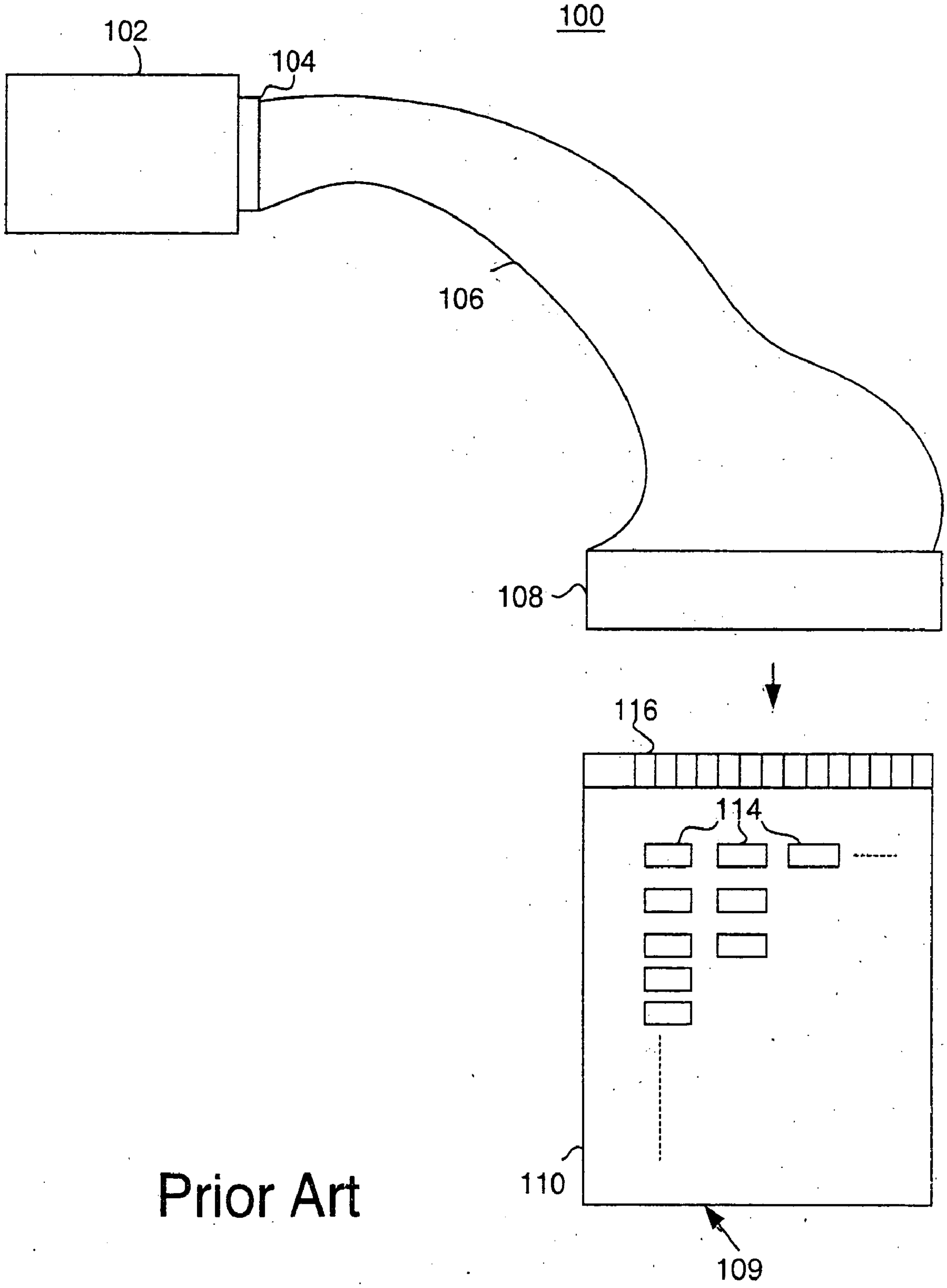
(57) **ABSTRACT**

An ultrasound imaging device comprising a two-dimensional array of ultrasound transducers cablelessly coupled to a signal generating and receiving unit such as a motherboard. The coupling includes an acoustically attenuating and electrically conductive structure, which can include posts that are electrically conductive or electrically insulative having a conductor embedded or mounted on the outer surface. There can also be a high density connector allowing coupling and de-coupling the two dimensional array to and from the motherboard.





Prior Art

FIG. 1

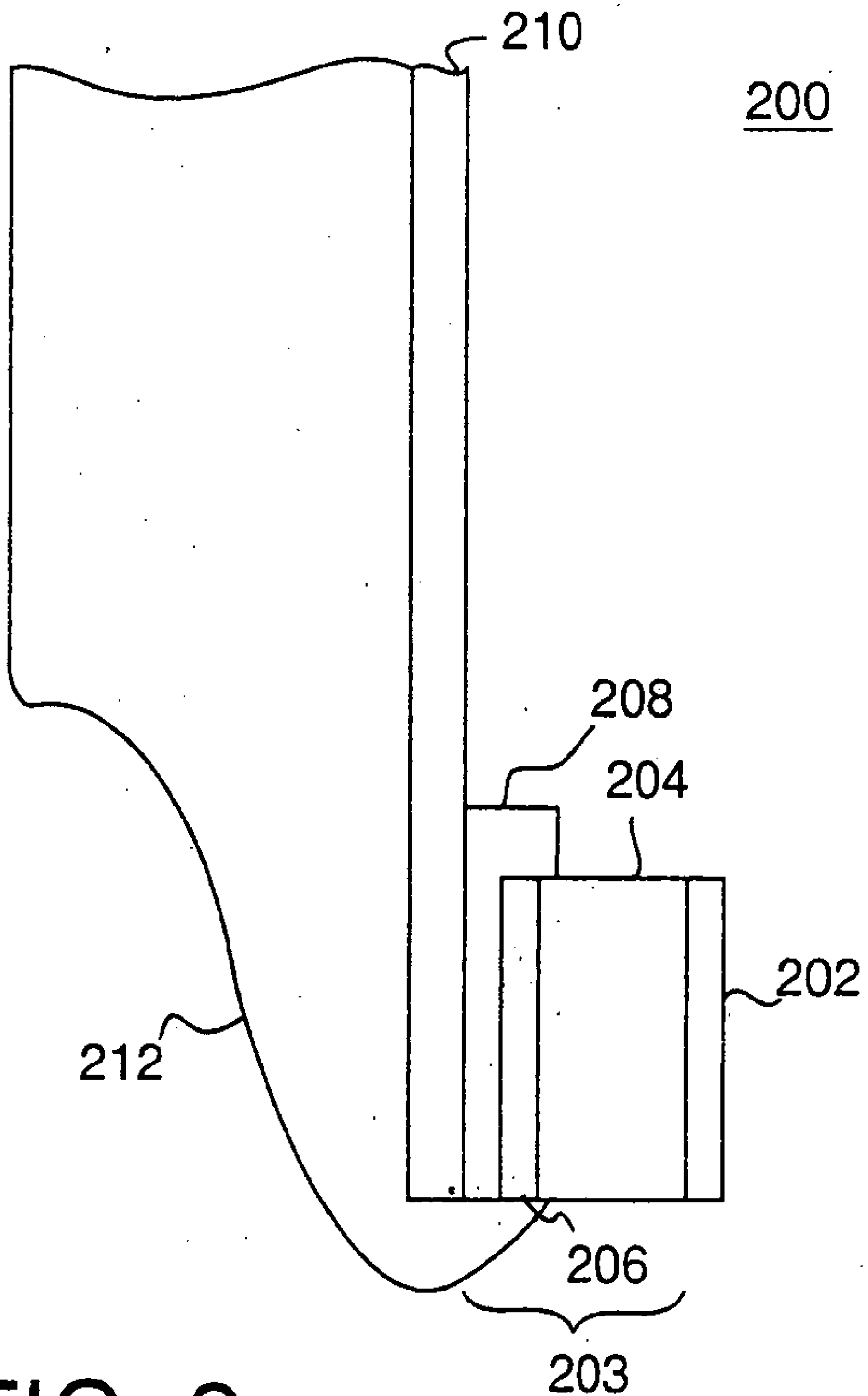


FIG. 2

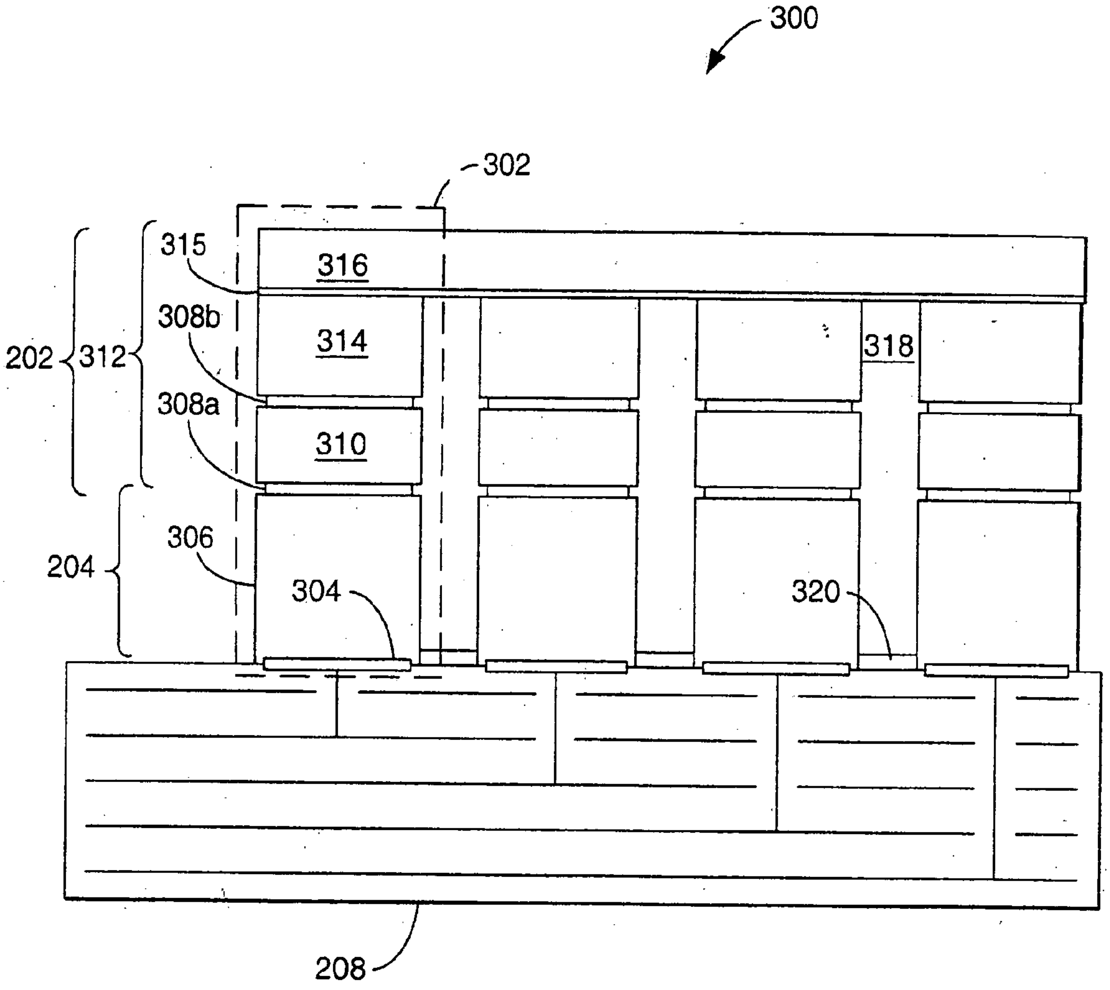

300
302
315
316
308b
314
202
312
318
308a
310
306
204
304
320
208

FIG. 3

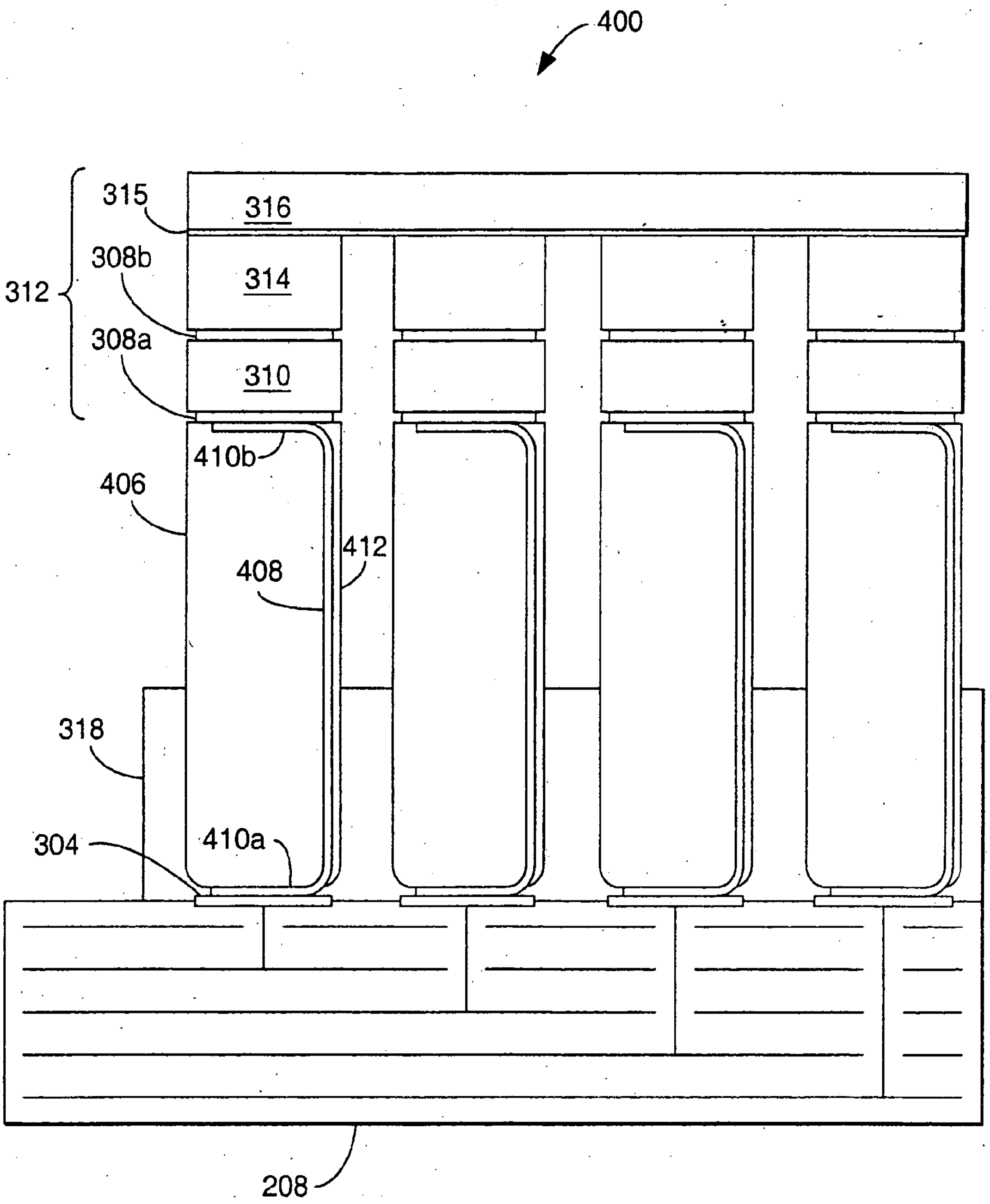

400
315
316
308b
314
312
308a
310
410b
406
412
408
318
304
410a
208

FIG. 4

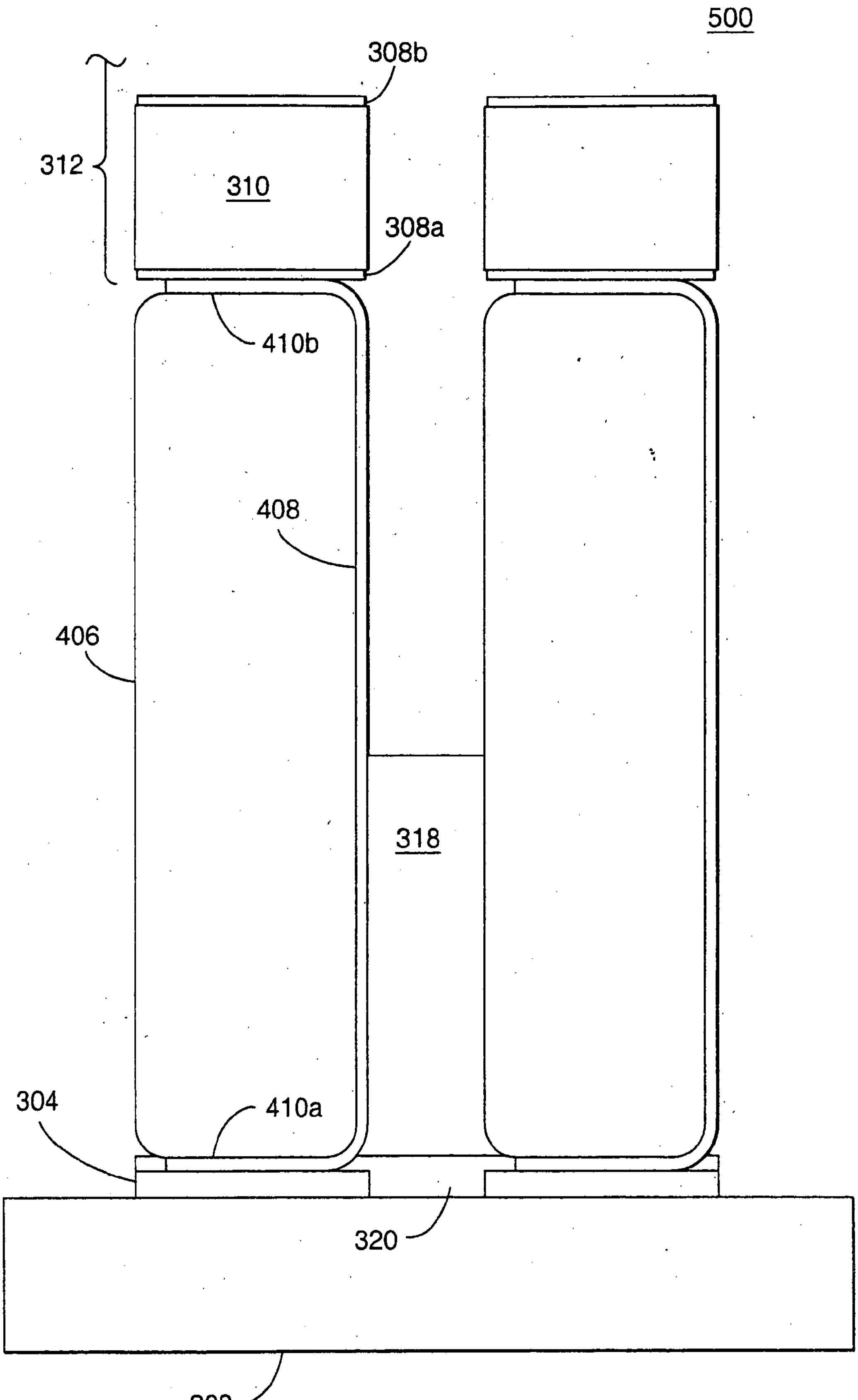


FIG. 5

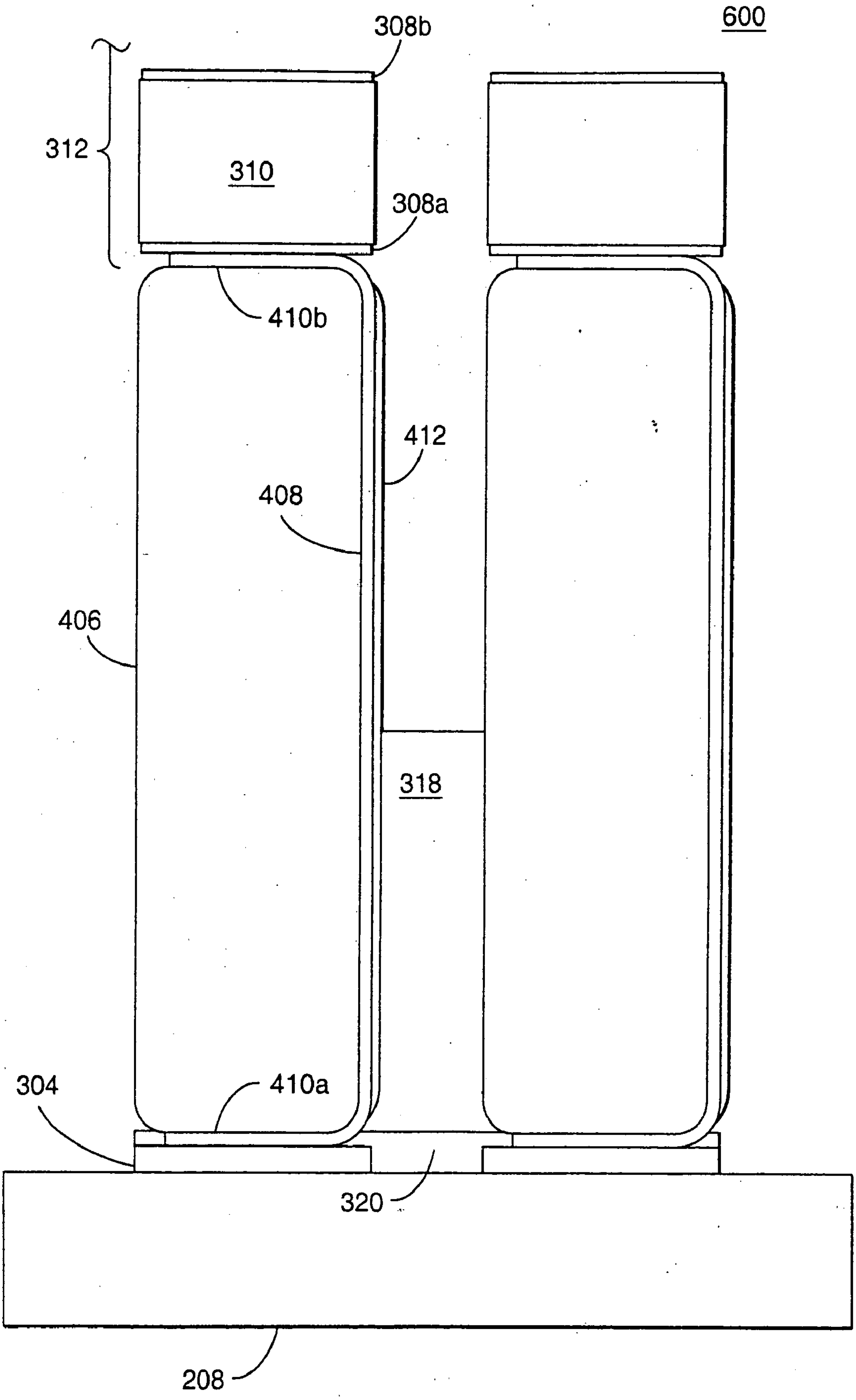


FIG. 6

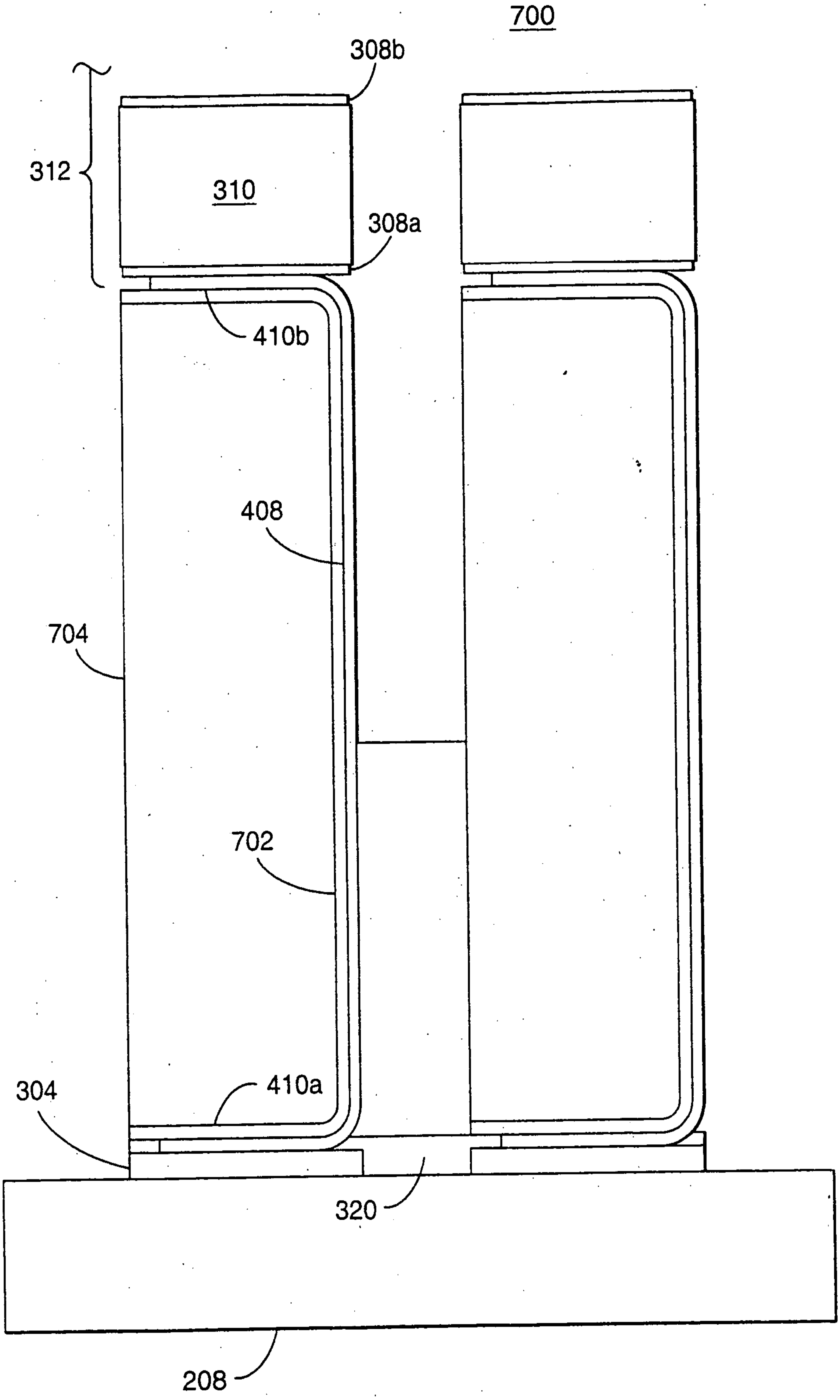


FIG. 7

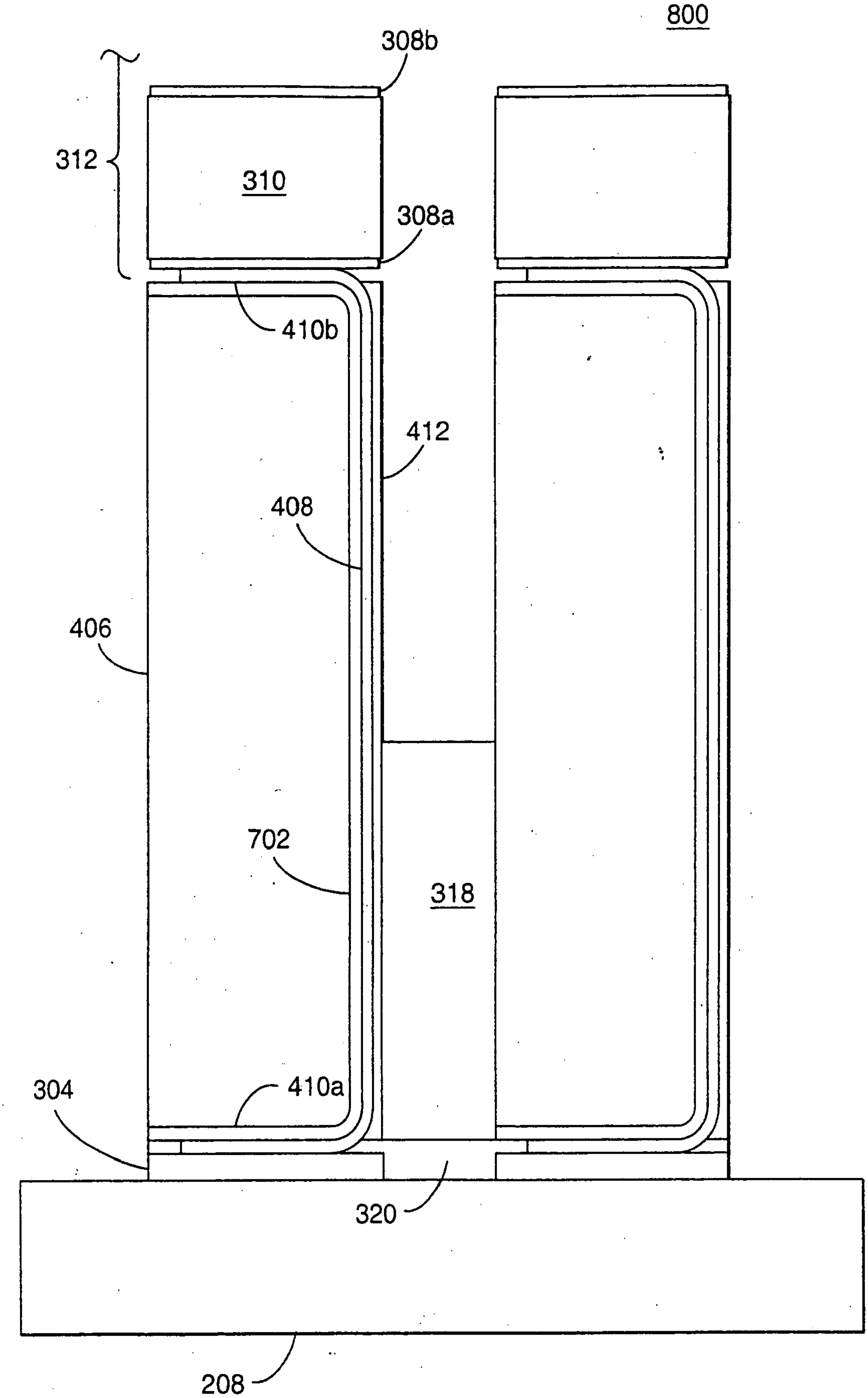


FIG. 8

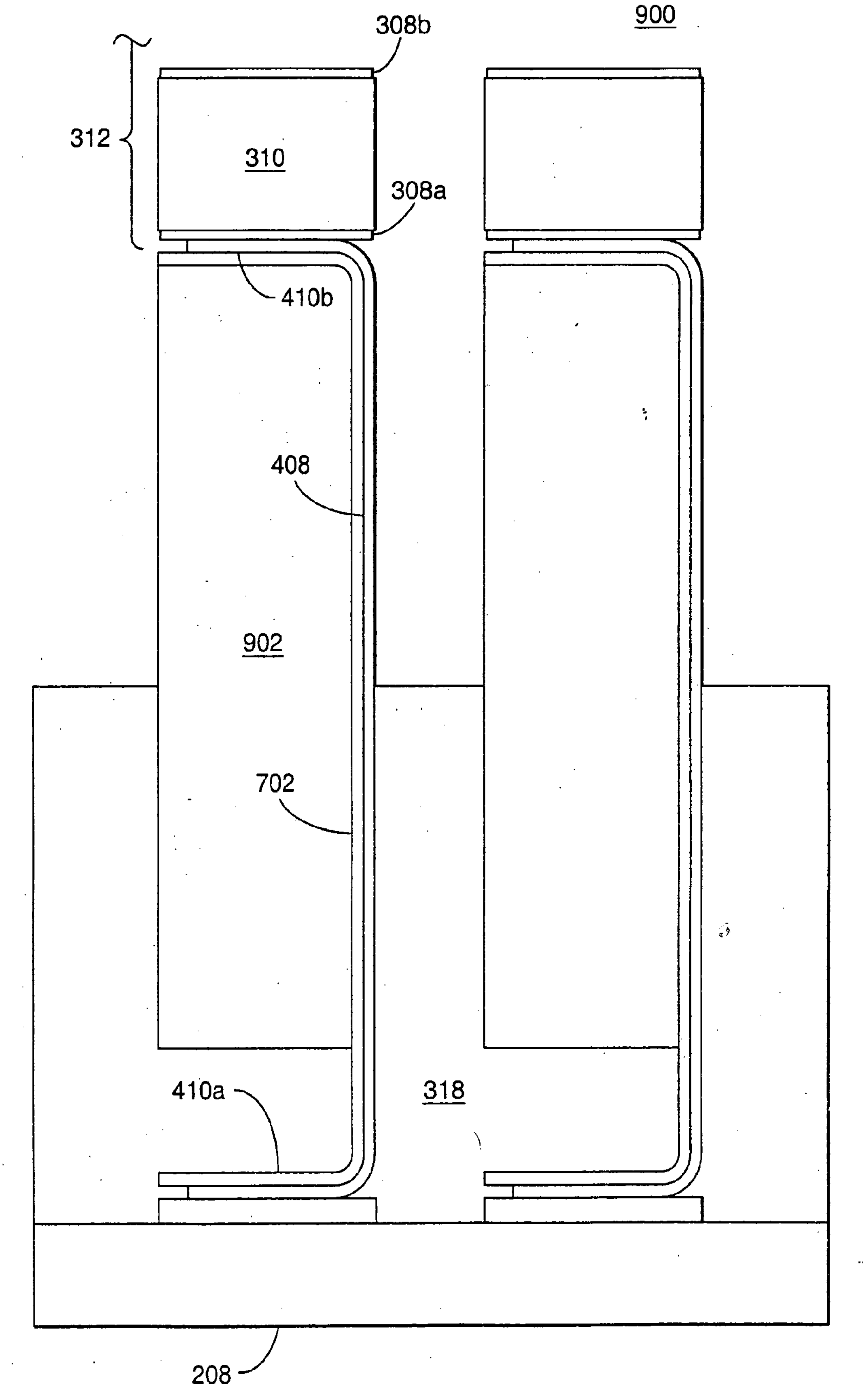


FIG. 9

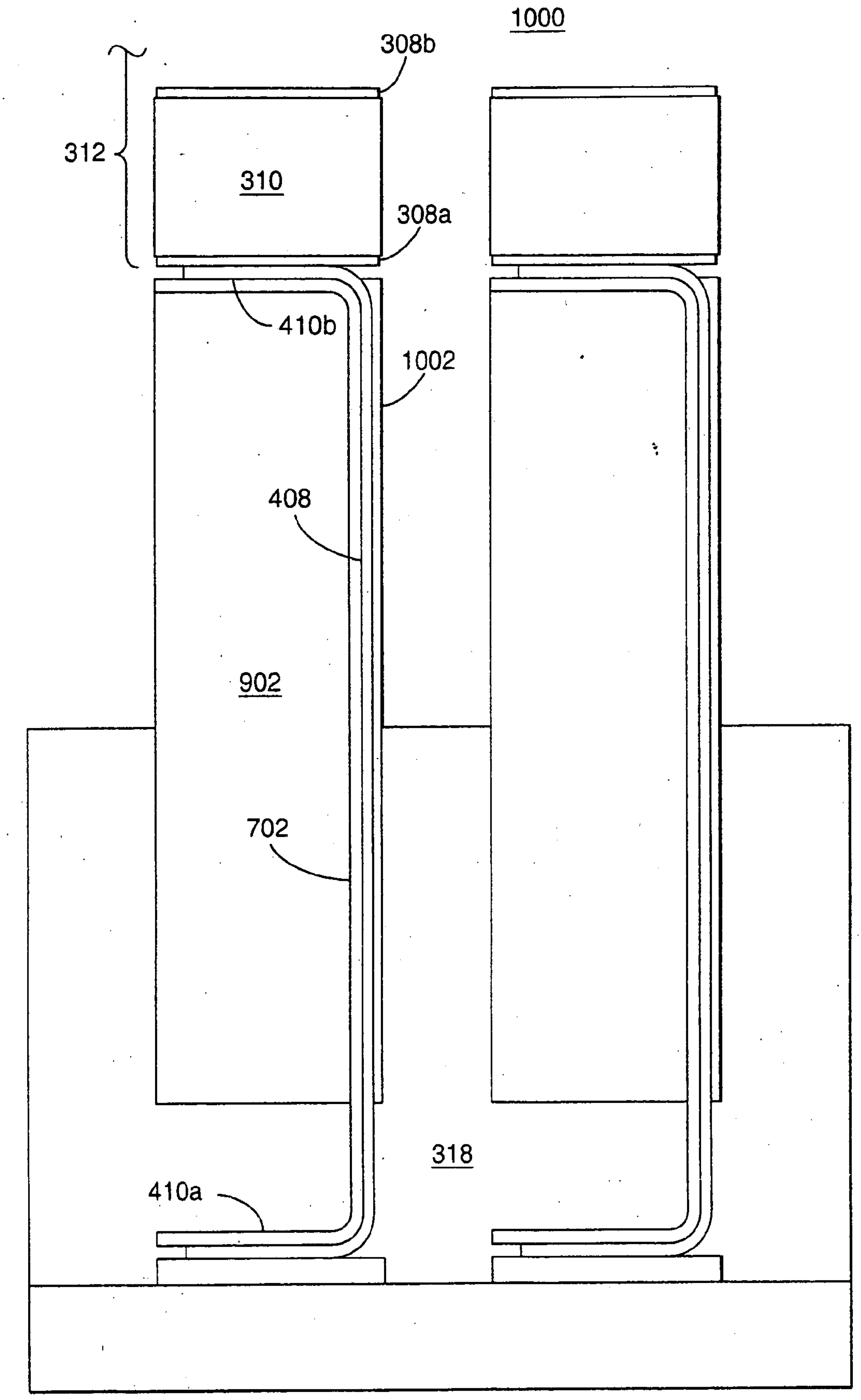


FIG. 10

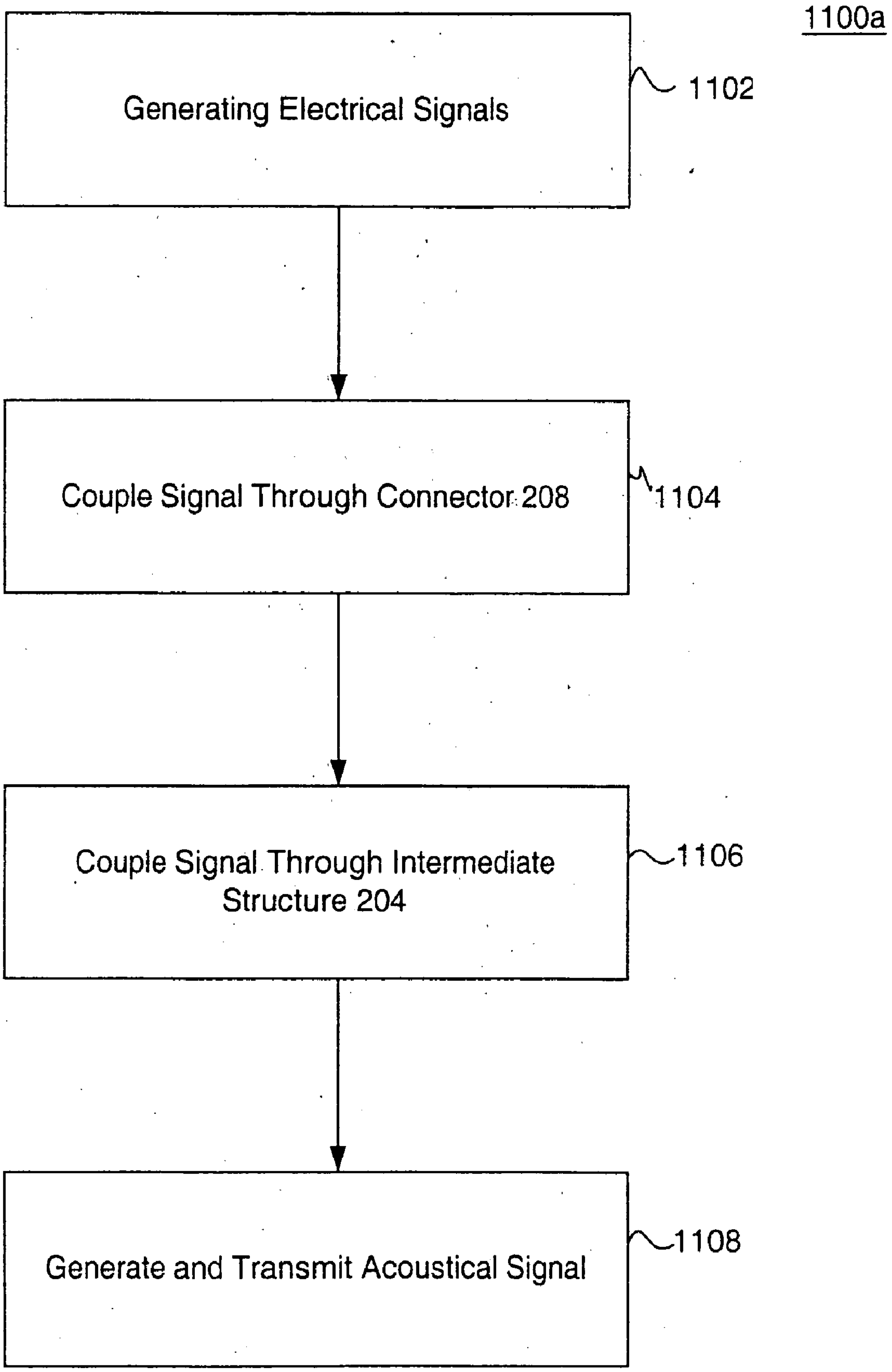

1100a
Generating Electrical Signals
1102
Couple Signal Through Connector 208
1104
Couple Signal Through Intermediate Structure 204
1106
Generate and Transmit Acoustical Signal
1108

FIG. 11A

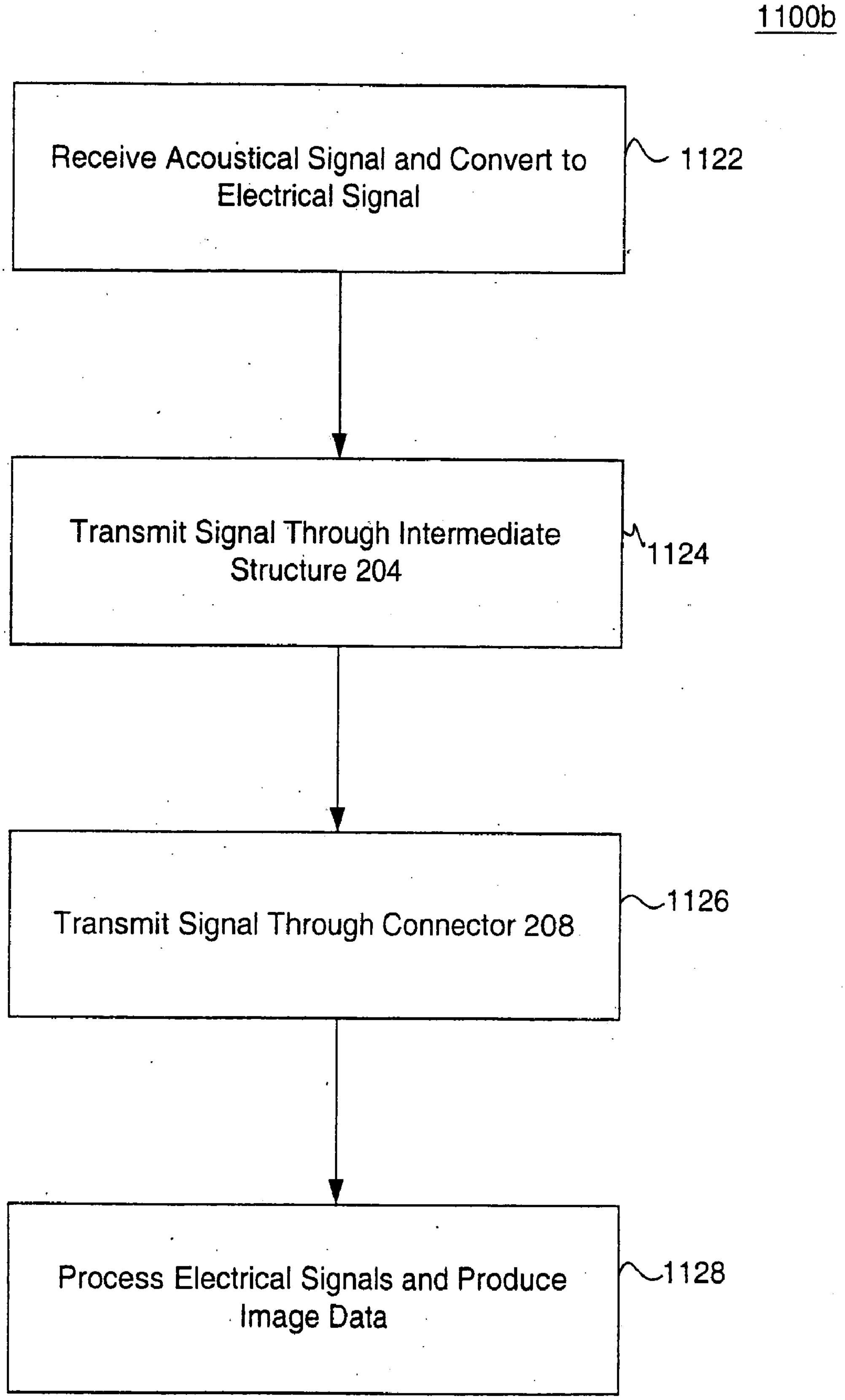

1100b
Receive Acoustical Signal and Convert to Electrical Signal
1122
Transmit Signal Through Intermediate Structure 204
1124
Transmit Signal Through Connector 208
1126
Process Electrical Signals and Produce Image Data
1128

FIG. 11B

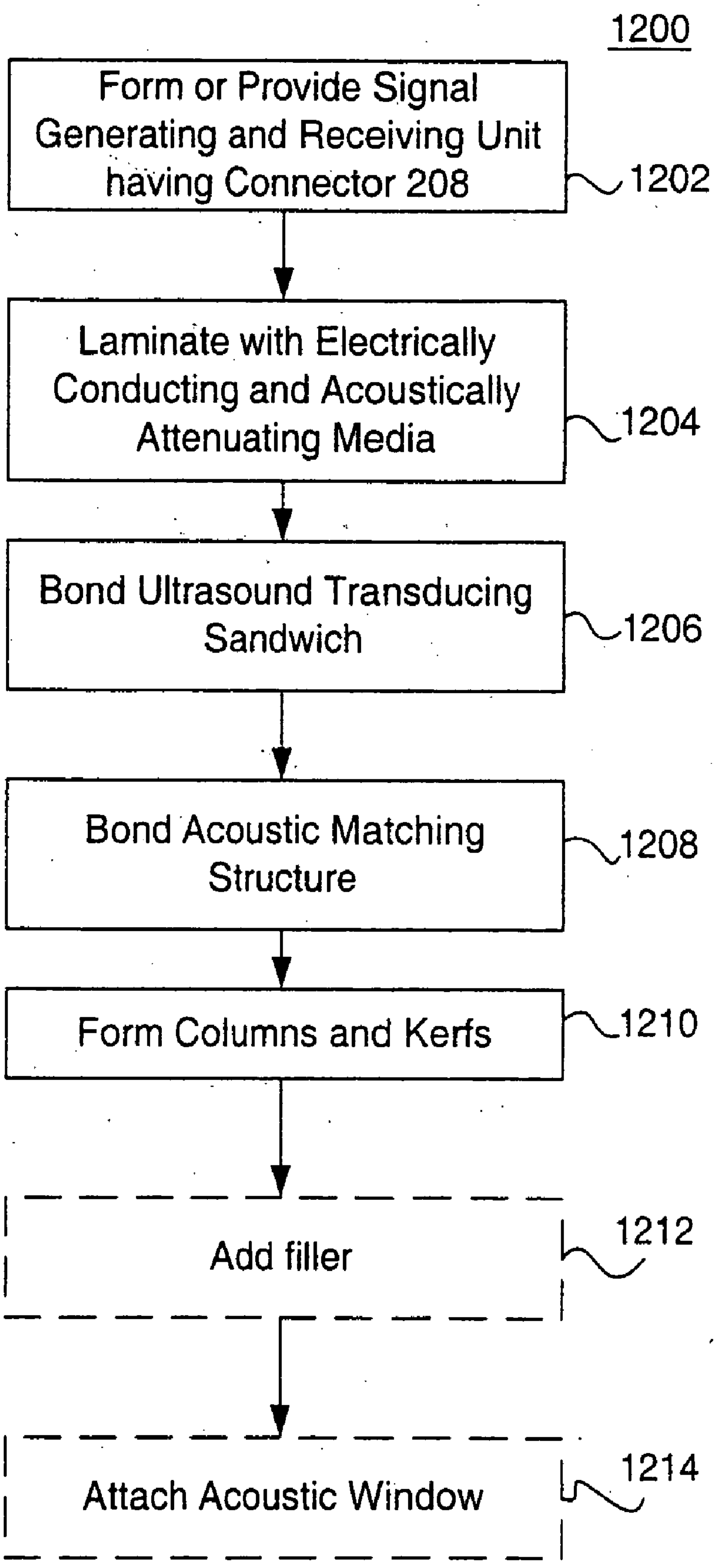

1200
Form or Provide Signal Generating and Receiving Unit having Connector 208
1202
Laminate with Electrically Conducting and Acoustically Attenuating Media
1204
Bond Ultrasound Transducing Sandwich
1206
Bond Acoustic Matching Structure
1208
Form Columns and Kerfs
1210
Add filler
1212
Attach Acoustic Window
1214

FIG. 12A

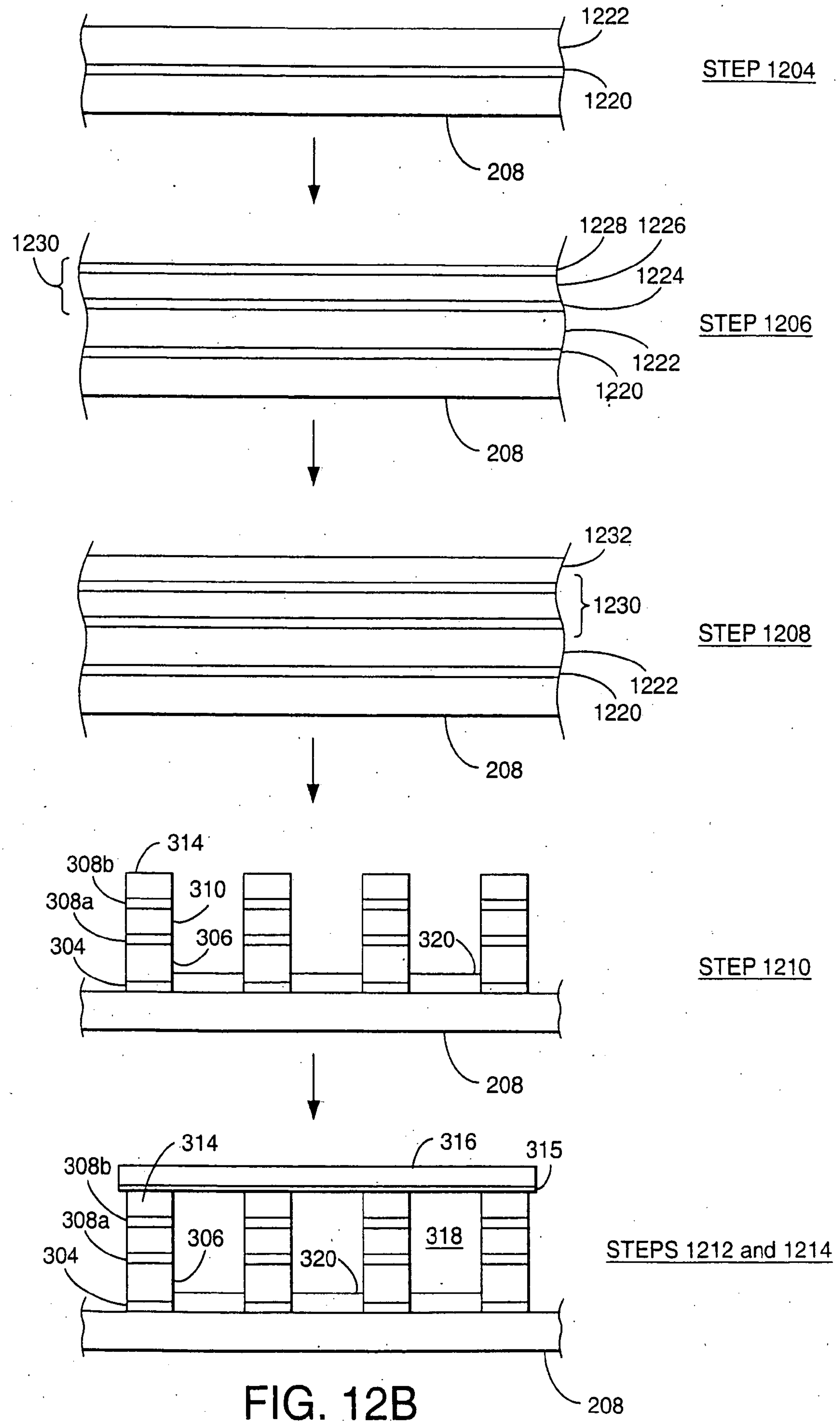

1222
STEP 1204
1220
208
1230
1228 1226
1224
STEP 1206
1222
1220
208
1232
1230
STEP 1208
1222
1220
208
314
308b
310
308a
306
320
304
STEP 1210
208
314
316
315
308b
308a
306
318
304
320
STEPS 1212 and 1214
208

FIG. 12B

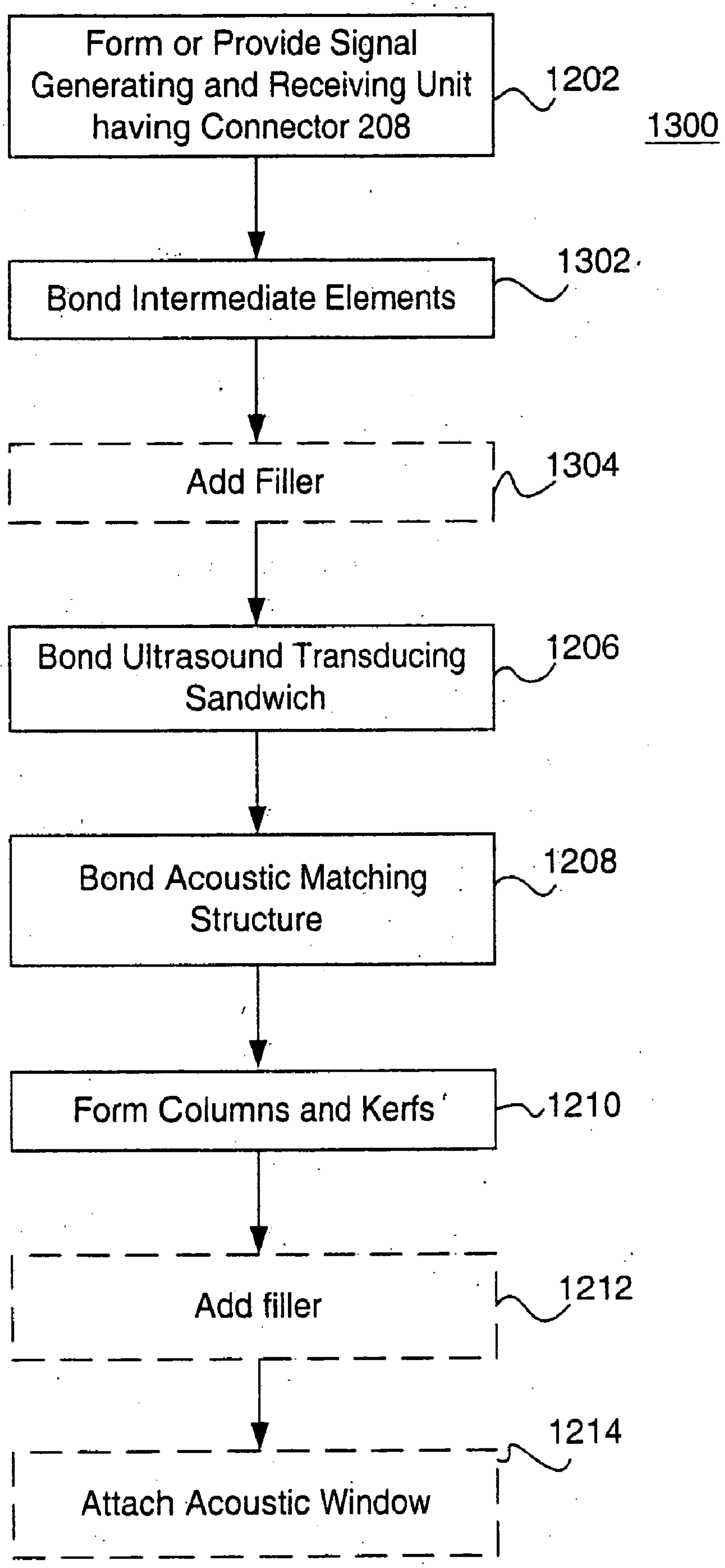

Form or Provide Signal Generating and Receiving Unit having Connector 208
1202
1300
Bond Intermediate Elements
1302
Add Filler
1304
Bond Ultrasound Transducing Sandwich
1206
Bond Acoustic Matching Structure
1208
Form Columns and Kerfs
1210
Add filler
1212
Attach Acoustic Window
1214

FIG. 13A

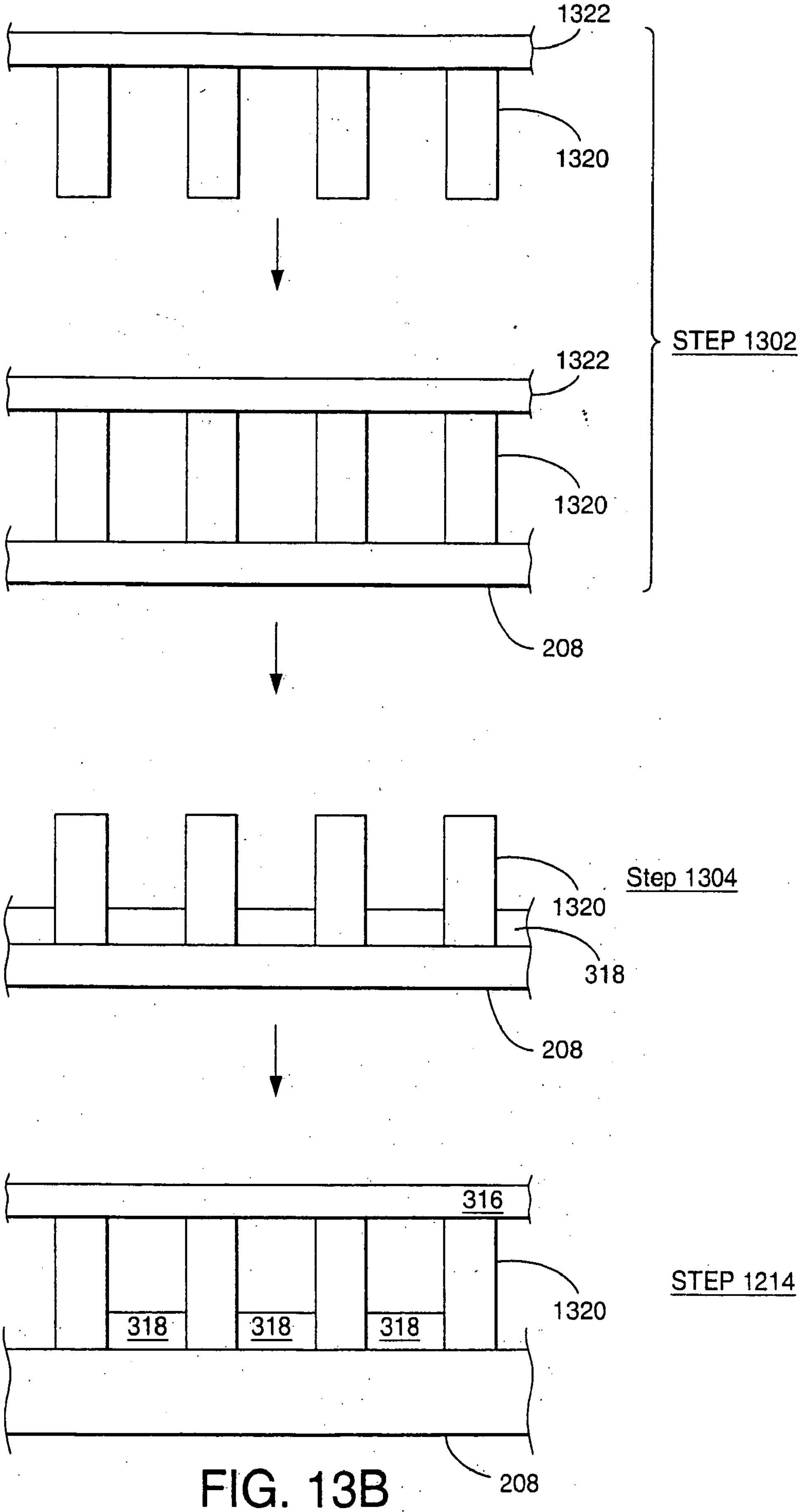

1322
1320
STEP 1302
1322
1320
208
Step 1304
1320
318
208
316
STEP 1214
1320
318
318
318
208

FIG. 13B

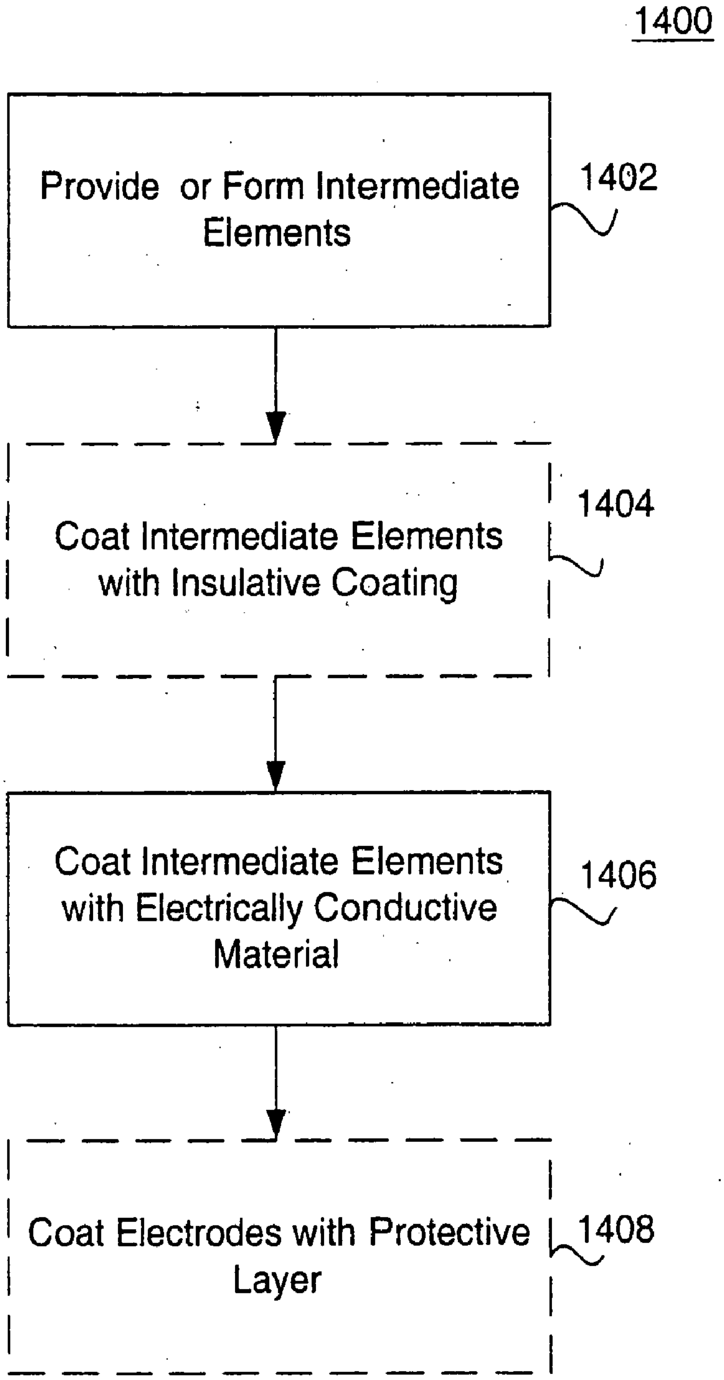

1400
Provide or Form Intermediate Elements
1402
Coat Intermediate Elements with Insulative Coating
1404
Coat Intermediate Elements with Electrically Conductive Material
1406
Coat Electrodes with Protective Layer
1408

FIG. 14

CABLELESS COUPLING METHODS FOR ULTRASOUND

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional application and claims the priority benefit of U.S. patent application Ser. No. 10/039,910, entitled "Ultrasound System with Cableless Coupling Assembly," filed Oct. 20, 2001 and now U.S. Pat. No. 6,______, which is a continuation-in-part application and claims the priority benefit of U.S. patent application Ser. No. 09/860,209, entitled "Miniaturized Ultrasound Apparatus and Method," filed May 18, 2001 and now U.S. Pat. No. 6,569,102, which is a continuation application and claims the priority benefit of U.S. patent application Ser. No. 09/378,175, entitled "Miniaturized Ultrasound Apparatus and Method," filed Aug. 20, 1999 and now U.S. Pat. No. 6,251,073. This application is also related to U.S. patent application Ser. No. 10/211,391, entitled "Broad Beam Imaging," and now U.S. Pat. No. 6,685,645. The disclosures of all these commonly owned applications are incorporated herein by reference.

BACKGROUND OF THE INVENION

[0002] 1. Field of the Invention

[0003] The invention is in the field of imaging devices and more particularly in the field of portable high-resolution three-dimensional ultrasonic imaging.

[0004] 2. Description of the Related Art

[0005] Ultrasonic imaging is a frequently used method of analysis. The technique is used to examine a wide range of materials and is especially common in medicine because of its relatively non-invasive nature, low cost, and fast response times. Typically, ultrasonic imaging is accomplished by generating and directing ultrasonic waves into a material under investigation. This ultrasonic imaging uses a set of ultrasound generating transducers and then observing reflections generated at the boundaries of dissimilar materials, such as tissues within a patient, also uses a set of ultrasound receiving transducers. The receiving and generating transducers may be arranged in arrays and are typically different sets of transducers but may differ only in the circuitry to which they are connected. The reflections are converted to electrical signals by the receiving transducers and then processed, using techniques known in the art, to determine the locations of echo sources. The resulting data is displayed using a display device, such as a monitor.

[0006] The beam intensity as a function of position may oscillate rather than fall off monotonically as a function of distance from the center of the beam. These oscillations in beam intensity are often called "side lobes." In the prior art, the term "apodisation" refers to the process of affecting the distribution of beam intensity to reduce side lobes. However, in the remainder of this specification the term "apodisation" is used to refer to tailoring the distribution of beam intensity for a desired beam characteristic such as having a Gaussian or sinc function distribution of beam intensity (without the side lobes).

[0007] Steering refers to changing the direction of a beam. Aperture refers to the size of the transducer or group of transducers being used to transmit or receive an acoustic beam.

[0008] The prior art process of producing, receiving, and analyzing an ultrasonic beam is called beam forming. The production of ultrasonic beams optionally includes apodisation, steering, focusing, and aperture. Using a prior art data analysis technique each ultrasonic beam is used to generate a one dimensional set of echolocation data. In a typical implementation, a plurality of ultrasonic beams is used to scan a multidimensional volume.

[0009] Typically, the ultrasonic signal transmitted into the material under investigation is generated by applying continuous or pulsed electronic signals to a transducer. The transmitted ultrasound is commonly in the range of 40 kHz to 10 MHz. The ultrasonic beam propagates through the material under investigation and reflects off of structures such as boundaries between adjacent tissue layers. As it travels, the ultrasonic energy may be scattered, resonated, attenuated, reflected, or transmitted. A portion of the reflected signals are returned to the transducers and detected as echoes. The detecting transducers convert the echo signals to electronic signals for processing using simple filters and signal averagers. After beam forming, an image scan converter uses the calculated positional information to generate two dimensional data that can be presented as an image. In prior art systems the image formation rate (the frame rate) is limited by at least the return time of an ultrasonic pulse. The pulse return time is the time between the transmission of ultrasound into the media of interest and the detection of the last reflected signals.

[0010] As an ultrasonic pulse propagates through a material of interest, additional harmonic frequency components are generated, which are analyzed and associated with the visualization of boundaries, or image contrast agents designed to re-radiate ultrasound at specific harmonic frequencies. Unwanted reflections within the ultrasound device can cause noise and the appearance of artifacts in the image.

[0011] One-dimensional acoustic arrays have a depth of focus that is usually determined by a nonadjustable passive acoustic focusing means that is affixed to each transducer. This type of focusing necessitates using different transducers for different applications with different depths of focus.

[0012] Two-dimensional transducer arrays used for high-speed three-dimensional imaging applications suffer from sensitivity loss caused by coupling multiple signal transfer and distribution systems to ultrasound systems. Two-dimensional transducers used for high-speed three-dimensional imaging applications must have a large number of pixels for two-dimensional steering capability with high resolution. High numbers of radiating/receiving pixels inevitably result in high electrical impedances per pixel in many types of transducers (e.g., piezoelectric, capacitive Micro Electro-Mechanical (MEM) transducers), making high-resolution two-dimensional arrays impractical.

[0013] To reduce the impedance, many prior art devices use a limited number of elements, or a one-dimensional array. In typical ultrasound systems, these high impedance elements are driven by a typical coaxial cable bundle carrying as many micro-coaxial cables as the number of pixels, with each micro-coaxial cable usually having 50-75 Ohm impedance. These cables do not directly interconnect to the individual elements of the two-dimensional array. Another level of interconnection in the form of multi-layer Printed Circuit Boards (PCBs) co-fired ceramic boards or multilayer flexes must transfer the signal to the transducer elements. The transducer elements are grouped into pixels each containing one or more transducer elements. For example, each pixel may contain one transmitting and one receiving transducer element. Systems including cables suffer from drawbacks that include, (1) the large number of required micro-coaxial elements makes the cable bundle unwieldy, and (2) the 50-75 ohm cable impedance cannot efficiently interface with or match the high electrical impedances of the individual transducer elements. These drawbacks result in impractically low sensitivity levels. The use of an additional multilayer transition device to connect from cables to transducer elements, introduces additional capacitive loading and crosstalk.

[0014] **FIG. 1** shows a prior art ultrasonic imaging device **100**, including a system **102**, a first connector **104**, a cable **106**, a second connector **108**, and a hand held unit **109**, which includes a multilayer structure **110** for transmitting the signal, interposing electrical connector structure (not shown), acoustic elements **114**, and pins **116**. System **102** may include a systems motherboard. The multilayer structure **110** could be a PCB, co-fired ceramic board, or flex circuits, for example. The interposing electrical connector structure (not shown) could be an interposing media for carrying signals from the multilayer structure **110** to acoustic elements **114**. The device of **FIG. 1** is bulky and can be difficult to move and manipulate because cable **106** has many wires in it and therefore interferes with movement. Cable **106** also needs to be thick and therefore does not bend easily. Handheld unit **109** has electrical contact pads **116** for individually powering the acoustic elements **114**.

SUMMARY OF THE INVENTION

[0015] An embodiment of the invention provides a miniaturized ultrasound system generating and receiving unit such as a motherboard with two-dimensional signal addressing capability whereby first connector **104**, cable **106**, and second connector **108** of the prior art device in **FIG. 1** can be eliminated. The system may have a system motherboard coupled via a cableless coupling to a transducer array. In one embodiment, the cableless coupling is also wireless (e.g., using the radio-frequency spectrum for transmitting and receiving data and signals). The system may include a two-dimensional surface interconnection between the transducer array and the signal generation and/or detection system, which eliminates the impractically thick and heavy cable. In one embodiment, the signal generation and/or detection system may be electrically matched to the transducer elements increasing the sensitivity more than were transducer elements not matched to the signal generation and/or detection system. The two-dimensional interconnection on the motherboard may be used without any other two-dimensional interconnection. In another embodiment, the electrical connection to the two-dimensional array elements are made via many flex circuits (e.g., printed circuit patterns using a layer of copper foil over a polymer base allowing for multidimensionality whereby the circuit may move, bend and twist without damage to the conductor), each coming from one row of elements, which may be terminated directly on the motherboard row of pads. Flex circuits should not be confused with ribbon cables (e.g., those cables made of normal, round insulated wires arranged side-by-side and fastened together by a cohesion process to form a flexible ribbon).

[0016] The two-dimensional array may perform multiple tasks. The motherboard system and the transducers may be designed to provide a sufficient percentage of the bandwidth for multiple frequency operations. For example, for many ultrasound transducers 100% of the bandwidth is necessary for multiple frequency operations. In an embodiment, the depth of focus is not fixed by the physical construction of the array, but is controlled by the area forming electronics and the system software, by active electrical phasing of the two-dimensional array elements. Alternatively, different transducers for different applications with different depths of focus can be used. Changing from one transducer to another can be facilitated by having a high density connector (i.e., a connector having a high density of connector contact pads, one pad for each transducer element (e.g., pixel) of the two-dimensional array) between the two-dimensional array and the system motherboard.

[0017] The invention may provide acoustically attenuating mounting posts with low electrical resistance, for example, and allow the two-dimensional arrays of acoustical elements to have a higher sensitivity than were the posts not present. The height of the posts allows the transducer to be oriented for convenient use even though it is an integral part of the motherboard, an other interconnection device, or an other system for example. The permanent connection with the motherboard requires the design of the transducer to provide sufficient bandwidth for multiple frequency operation.

[0018] In one embodiment the two-dimensional array is permanently integrated with the motherboard. The depth of focus of the two-dimensional array is not fixed by the physical construction of the array, but is controlled by the area forming electronics and system software, which determine the active phasing of the two-dimensional array elements. This method of control eliminates the necessity of using different transducers for different applications with different fixed depths of focus and allows one transducer affixed to the motherboard, for example, to perform multiple tasks. In another embodiment of this invention different two-dimensional arrays with different depths of focus, frequency, and other characteristics can be plugged to the system motherboard without an intervening cable via the high density connector.

[0019] Broad beam technologies refer to systems and methods that include or take advantage of techniques for generating ultrasound and analyzing detected echoes such that multidimensional spatial information obtainable from a single ultrasonic pulse.

[0020] Area forming is the process of producing, receiving, and analyzing an ultrasonic beam, that optionally includes apodisation, steering, focusing, and aperture control, where a two dimensional set of echolocation data can be generated using only one ultrasonic beam. Nonetheless, more than one ultrasonic beam may still be used with the area forming even though only one is necessary. Area forming is a process separate and distinct from beam forming. Area forming may yield an area of information one transmit and/or receive cycle, in contrast to beam forming that typically only processes a line of information per transmit and/or receive cycle. Alternatively, beam forming can be used instead of area forming electronics throughout this application.

[0021] Volume forming is the process of producing, receiving, and analyzing an ultrasonic beam, that optionally includes apodisation, steering, focusing, and aperture control, where a three dimensional set of echolocation data can be generated using only one ultrasonic beam. Nonetheless, multiple ultrasonic beams may be used although not necessary. Volume forming is a superset of area forming.

[0022] Multidimensional forming is the process of producing, receiving, and analyzing an ultrasonic beam, that optionally includes apodisation, steering, focusing, and apertures, wherein a two or more dimensional set of spatial echolocation data can be generated using only one ultrasonic beam. Nonetheless, multiple ultrasonic beams may be used although not necessary. Multidimensional forming optionally includes non-spatial dimensions such as time and velocity.

[0023] In the above discussion although the motherboard is specified as the signal generating and receiving unit, it is only by way of example and any signal generating and receiving unit can be used.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] **FIG. 1** is a prior art ultrasound device;

[0025] **FIG. 2** is an overview of an embodiment of the invention;

[0026] **FIG. 3** shows the details of the structure of **FIG. 2** according to an embodiment of the invention;

[0027] **FIG. 4** is an alternative embodiment of the structure of **FIG. 2**;

[0028] **FIG. 5** is a more detailed illustration of **FIG. 4**;

[0029] **FIG. 6** is another embodiment of the structure of **FIG. 2**;

[0030] **FIG. 7** is another embodiment of the structure of **FIG. 2**;

[0031] **FIG. 8** is another embodiment of the structure of **FIG. 2**;

[0032] **FIG. 9** is another embodiment of the structure of **FIG. 2**;

[0033] **FIG. 10** is another embodiment of the structure of **FIG. 2**;

[0034] **FIG. 11A** is a flowchart of a method of transmitting an acoustic signal;

[0035] **FIG. 11B** is a flowchart of a method of receiving an acoustic signal;

[0036] **FIG. 12A** is a flowchart of a method of making an embodiment of the invention;

[0037] **FIG. 12B** illustrates the structure at various stages of the method of **FIG. 12A**;

[0038] **FIG. 13A** is a flowchart of a method of making an embodiment of the invention of **FIGS. 4-10**;

[0039] **FIG. 13B** illustrates the structure at various stages of the method of **FIG. 13A**; and

[0040] **FIG. 14** is a flowchart of a method for making intermediate elements of an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0041] **FIG. 2** is an overview of one embodiment of the invention. **FIG. 2** shows a handheld ultrasound device **200** that includes an ultrasound transducing structure **202** coupled via a cableless coupling **203** to a signal generating and receiving unit **210**. The cableless coupling **203** includes an intermediate structure **204**, an electrically conducting structure **206**, and a connector **208**. The connector **208** is coupled to the signal generating and receiving unit **210**, which are secured within housing **212**, and cooperates with cableless coupling **203**.

[0042] The signals from or to intermediate structure **204** pass through electrically conducting structure **206**, connector **208**, and the signal generating and receiving unit **210**. Ultrasound transducing structure **202** generates, or pulses, in response to signals received via intermediate structure **204**, or receives ultrasonic waves and converts them to electrical signals, then sends them to intermediate structure **204**.

[0043] In an embodiment cableless coupling **203** is also wireless. Signal generating and receiving unit **210** can be an integrated circuit or a system including a motherboard and may also include one or more child boards, for example. Intermediate structure **204** is an electrically coupled and acoustically isolating structure that serves to reduce crosstalk between the elements of the ultrasound transducing structure **202**. Additionally, intermediate structure **204** protects ultrasound transducing structure **202** from external or internal acoustical noise and conducts the electrical signal to ultrasound transducing structure **202**.

[0044] Ultrasound transducing structure **202**, intermediate structure **204**, and electrically conducting structure **206** may be divided into multiple elements that may be arranged in a periodic lattice. The lattice may be rectangular or hexagonal, for example. Electrically conducting structure **206** may be pads or may be interlocking male and female pins, for example, joining intermediate structure **204** and connector **208**. Signal generating and receiving unit **210** may be a system motherboard, for example, and may have a connector **208** that can be a Printed Circuit Board (PCB), co-fired ceramic board, or the like, for signal transmission and distribution. Connector **208** may be a separate component attached to signal generating and receiving unit **210** or may be an integral part of signal generating and receiving unit **210**. For example, connector **208** may be a connector region coupled to or on a motherboard. (Throughout this specification the word "on" is to be understood as generic to being an integral part of and to being a separate structure that allows two structures to be attached together. Thus, whenever the specification discusses the connector **208** being "on" signal generating and receiving unit **210** it is to be read as generic to connector **208** being an integral part of and being a separate structure attached to signal generating and receiving unit **210**.) Signal generating and receiving unit **210** may include one or more signal processors. The small size of the handheld ultrasound device may allow ultrasound transducing structure **202** to be easily positioned for imaging at a variety of angles.

[0045] Alternatively, a section of housing **212** can be made of a flexible material to allow the positioning of the transducer structure **202**. Signal generating and receiving unit **210** may be kept small enough and/or may have a section that is made from flexible material to allow handheld ultrasound unit **200** to be flexed, thereby allowing ultrasound transducing structure **202** to be easily positioned for imaging.

[0046] **FIG. 3** shows the details of the structure of **FIG. 2** according to one embodiment of the invention. The **FIG. 3** embodiment, which is a first embodiment **300**, includes transducer **302** having electrical pads **304**, intermediate elements **306**, electrical contacts **308***a* and *b*, which sandwich there between an active acoustic element **310**, acoustic transducing element **312**, acoustic matching element **314**, ground sheet **315**, optional acoustic window **316**, optional filler **318**, and optional adhesive **320**.

[0047] Connector **208** on signal generating and receiving unit **210** of the ultrasound system is coupled to transducer **302**. The collection of electrical pads **304** are one embodiment of electrically conducting structure **206**. In an embodiment, a two-dimensional array of all electrical pads **304** make up electrically conducting structure **206**, and are coupled to intermediate elements **306**, which make up intermediate structure **204**. Electrical pads **304** can be pure materials, alloys, or any mixture of chromium, nickel, silver, copper, gold, tin, tin oxide, indium and/or indium oxide, or any conductive material, for example. Acoustic transducing element **312** includes electrical contacts **308***a* and *b*, which sandwich there between an active acoustic element **310**. Active acoustic element **310** can be made with any acoustically active material (i.e., any material capable of converting a sound signal to an electrical signal and visa versa) such as piezoelectric materials such as quartz, lithium niobate, lithium sulfate, ceramic materials, lead zirconate titanate, barium titanate, and lead metaniobate, or other sound generating devices such as micro-machined structures. Electrical contacts **308***a* and *b* can be made from materials including, pure materials, alloys, or any mixture of chromium, nickel, silver, copper, gold, tin, tin oxide, indium and/or indium oxide, or any conductive material, for example.

[0048] The sandwich of active acoustic element **310** and electrical contacts **308***a* and **308***b* form an acoustic transducing element **312** for generating and/or receiving ultrasound. In the case of a micro-machined device, the sandwich of active acoustic element **310** and electrical contacts **308***a* and **308***b* may be replaced by the micro-machined element and its contacts, which may or may not have a sandwich structure. Acoustic transducing element **312** may also include an acoustic matching element **314** and an optional acoustic window **316**. Optional acoustic window **316** may provide electrical isolation protecting a media of interest, such as a patient, from electrical shock. Optionally, acoustic matching element **314** may provide electrical isolation instead of, or in addition to, the electrical isolation provided by optional acoustic window **316**. Acoustic matching element **314** may be an assembly of acoustic matching subelements. For example, acoustic matching element **314** may have several different layers. Acoustic matching element **314** may be made from materials or mixtures of materials with acoustic matching properties. In an embodiment, acoustic matching element **314** electrically couples electrical contact **308***b* to ground sheet **315** thereby providing a return to ground. Alternatively, ground sheet **315** need not be included because optional acoustic window **316** can be made from a conductive material and act as a ground sheet. Further, alternatively, electrical contacts **308***b* may be electrically coupled together forming one sheet, for example, that may be used for a return to ground. In this alternative embodiment, acoustic matching element **314** may or may not be conductive. Joining electrical contacts **308***b* into one sheet increases the difficulty of acoustically isolating transducers **302**. But if the acoustical impedance of the conductive material joining electrical contacts **308***b* is mismatched, for example, acoustic isolation can be achieved despite the joining material. Optional filler **318** may be placed between intermediate elements **306**, completely or partially filling the voids or kerfs (i.e., the spaces between transducers **302**). Optional filler **318** may be epoxy resin or other polymers and may include additives to modify filler characteristics. An optional adhesive **320** may be used to secure transducer **302** via electrical pads **304** to connector **208**. Optional adhesive **320** may be insulating or conducting adhesives such as epoxy, polyurethane, or silicone with or without various additives for different properties.

[0049] Transducers **302** differ from prior art transducers in that they are mounted directly to connector **208** of signal generating and receiving unit **210**. Alternatively, structures of intermediate elements **306** that are different from the prior art may also be used.

[0050] In another embodiment transducer **302** is mounted on a high density connector (not shown), which is plugged into a corresponding connector **208** of the signal generating and receiving unit **210**. The high density connector allows the acoustic transducing element **312** to be positioned further from connector **208**. Structures of intermediate elements **306** are further discussed below. Also, the close proximity of transducers **302** to connector **208** may affect the structural, acoustical, and electrical requirements of transducers **302**. Consequently, the set of elements that produce optimal performance for transducers **302** may be different than those of similar prior art transducers.

[0051] Intermediate elements **306** may serve as posts or columns, and can have a cross section of any shape. For example, the cross section of intermediate elements **306** can be square, rectangular, circular, ovular, triangular, diamond-like, trapezoidal, rhombus-like, or polygonal in shape. Intermediate elements **306** can be a mixture of any of, any combination of, or all of epoxy, polyurethane, and/or silicone, for example. Intermediate elements **306** may also contain heavy particles of any shape or spheres made from material such as tungsten, and may further contain light particles, bubbles, and/or microspheres, which help attenuate sound. The light particles and microspheres can be made from glass and/or plastic, for example. Additionally, intermediate elements **306** may contain graphite or other electrically conductive particles, which also help attenuate sound. Electrically conductive particles could be used as some or all of the heavy and/or light particles, depending on the ranges of density of the conducting particles chosen.

[0052] The signal from signal generating and receiving unit **210** is brought through the layers and structures of connector **208** to electrical pads **304** on connector **208**'s surface. Electrical pads **304**, intermediate elements **306**, and acoustic transducing elements **312** may be stacked one on top of the other and form the above-mentioned two-dimensional lattice. Acoustic transducing elements **312** may transform the electrical signals to sound waves, or may convert acoustic sound waves to electrical signals. Acoustic transducing elements **312** may be arranged in the same lattice as electrical pads **304**, and electrically addressed via signal distribution within signal generating and receiving unit **210**.

[0053] Intermediate elements **306** form an interconnecting backing media that transmits electrical signals between electrical pads **304**, on connector **208** of signal generating and receiving unit **210**, and electrical contacts **308***a*, on acoustic transducing elements **312**. Intermediate elements **306** may have an electrical conductivity that is high enough to minimize signal loss. The signal loss due to the intermediate element **306** is the power loss (I^2R, where I is the total current flowing through the array of intermediate elements **306** and R is effective resistance of the array of intermediate elements **306**) caused by the resistance of the intermediate element. For example, in an embodiment the conductivity of the intermediate element is adjusted so that the signal loss is kept less than 1 DB.

[0054] The total length of the interconnecting media in the direction perpendicular to connector **208** on signal generating and receiving unit **210** and the resistivity of this media are the main factors determining the total resistance of each electrical coupling between acoustic transducing elements **312** and electrical pads **304**. Thus, the resistivity of the intermediate elements **306** limits the elements' length, which in turn limits the intermediate structure **204**'s thickness. Intermediate elements **306** may have adequate acoustical attenuation or impedance to avoid sound reflections from connector **208** of the signal generating and receiving unit **210** that would otherwise reach acoustic transducing elements **312**. Intermediate elements **306** may provide mechanical integrity and positioning accuracy of acoustic transducing elements **312** and connector **208** of signal generating and receiving unit **210**.

[0055] The interconnecting backing media used for intermediate elements **306** may be an electrically anisotropic conducting media that conducts electricity in a direction perpendicular to the surface of the electrical pads **304**. The interconnecting backing media may be used to bond acoustic transducing elements **312** to electrical pads **304** on connector **208** of signal generating and receiving unit **210**. Intermediate elements **306** may be made from an electrically conductive and acoustically lossy media. An appropriate anisotropic electrical conduction media can be made by incorporating a sparse concentration of conducting elements and/or particles into an electrically insulating medium. The density of the sparse concentration is such that the conducting elements and/or particles do not touch each other in a direction perpendicular to the flow of electrical current due to their low density. The conducting elements and/or particles may have an elongated shape, and the conducting elements are oriented with their longer dimension to reach and make electrical contact on either side of the insulating medium in which they are located. The elements can be whiskers, wires, or arbitrary shapes of conducting media tending to extend the entire length of intermediate element **306**. Alternatively, the conducting elements and/or particles may be significantly shorter than and kept relatively parallel to the long direction of intermediate elements **306**. The conductive elements should be long enough so that at least a significant number of them tend to touch one another along the length of the particles, but not along the width. The use of an anisotropic conductor reduces the chances of shorting between adjacent intermediate elements **306** when compared to an isotropic conductor.

[0056] Alternatively, an isotropic electrically conducting and acoustically appropriate medium may be used to bond the array of acoustic transducing elements **312** to the two-dimensional array of electrical pads **304**. Electrical shorts between the intermediate elements **306** can be removed by eliminating the excess media causing the short via mechanical dicing, various ion, electron, plasma, chemical erosion, or other processes.

[0057] Optional filler **318** may be an insulator that helps minimize electrical shorting and may have suitable acoustical impedance to prevent crosstalk between transducers **302**. It may be desirable to minimize crosstalk by leaving the kerfs near transducers **302** void of filler. Optional filler **318** can be an acoustically attenuating material or a material with a highly mismatched acoustical impedance to transducer **302**.

[0058] Optional adhesive **320** can be conductive or insulative. If optional adhesive **320** is conductive, it is placed primarily between electrical pads **304** and intermediate element **306**. Typically any excess optional adhesive **320** would be removed from the kerfs. However, it is not necessary to remove all of optional adhesive **320** from the kerfs even if it is conductive. The thinner a conductive film the more resistive it is to currents traveling in a plane. Also, the thinner a conductive film the more breaks, or discontinues, it is likely to have in it. Consequently, if any of optional adhesive **320** is conductive and is in the kerfs, the optional adhesive **320** must be thin enough or have enough breaks so that it will act as an insulator in a direction parallel to the surface of connector **208** having electrical pads **304**, and the optional adhesive **320** must not cause any shorting.

[0059] Similarly, if optional adhesive **320** is insulative, it is placed primarily in the kerfs. Typically, all of optional adhesive **320** on electrical pads **304** are removed. However it is not necessary to remove all of optional adhesive **320** from the electrical pads **304**, even if it is insulative. The thinner an insulative film, the more likely it will be able to support a current traveling perpendicular to its surface via arcing, tunneling, or breaks in the insulative film, for example. Consequently, if optional adhesive **320** is insulative, the portion placed on electrical pads **304** must be thin enough or have enough holes in it to allow the flow of a current through it (such as by contact, arcing, or tunneling). Pressure applied while bonding intermediate elements **306** can be used to squeeze excess adhesive out from between the electrical pads **304** and the intermediate elements **306**.

[0060] In **FIGS. 4-10** like components have been given the same alphanumerical labels. To simplify the drawings **FIGS. 5-10** show no acoustic matching element **314**, ground sheet **315**, or optional acoustic window **316**, although they are present as in **FIGS. 3 and 4**. **FIGS. 4-10** also share the same ultrasound transducing structure **202** and signal generating and receiving unit **210** as in **FIG. 3**. **FIGS. 5-10** differ from one another primarily in the make up of intermediate structure **204**.

[0061] **FIG. 4** is an alternative embodiment **400** of the structure of **FIG. 2**. Embodiment **400** has intermediate elements **406**, which are insulative and coated with a conductor **408** on any number of sides greater than two, including conductive pads **410***a* and **410***b* located at both ends. Specifically, to explain what is meant by conductor **408** being coated on any number of sides greater than two, conductive pads **410***a* and **410***b* cover intermediate elements **406** on at least part of each of two of its ends. A portion of conductor **408** must also be placed at least partially on a third side of intermediate elements **406** to form an electrical coupling between conductive pads **410***a* and **410***b*. Intermediate elements **406** may be columns or posts made from a mixture of any of, any combination of, or all of, epoxy, polyurethane, and/or silicone containing dense particles or spheres made from material such as, but not limited to, tungsten and bubbles, low density particles, and/or microspheres. The low density particles and microspheres may be made from glass and/or plastic, for example. Conductor **408** may be a thin film that provides electrical interconnection between acoustic transducing elements **312** and electrical pads **304** to which it is bonded or soldered. The conductor **408** may be exposed or covered. If conductor **408** is covered, it may be embedded within, intermediate elements **406** and/or covered by optional film **412**. Optional film **412** allows for the removal of any subsequently introduced optional filler **318** by mechanical means, such as dicing wheels, without the danger of damaging conductor **408**. Optional film **412** may be a thin film of insulating material or the same material as intermediate elements **406**. Conductor **408** may be replaced by conducting wires or whiskers that may be placed along the edges of, or embedded within intermediate elements **406**. Optional filler **318** may encapsulate conductor **408** completely, or partially, as shown in **FIG. 4**. Optional filler **318** may serve the purposes of providing structural integrity and acoustically isolating individual acoustic transducing elements **312**. Optional filler **318** may be of the same material as the posts used for intermediate elements **406** as long as it is insulative, or does not short transducers **302**; the higher the electrical conductivity of conductor **408**, the lower the signal's loss. In one embodiment, the electrical conductivity provided by conductor **408** may be made high enough to minimize signal loss. The total length of intermediate elements **406** in the direction perpendicular to the signal generating and receiving unit **210**, and the per length resistance of conductor **408**, will determine the total resistance of the individual couplings between the acoustic transducing elements **312** and electrical pads **304**. Due to the relatively high conductivity of metallic films or wires, it is practical to increase the thickness of intermediate structure **204**, to position the acoustic array surface to touch the patient in a comfortable way. Intermediate elements **406** may serve as posts or columns and can have a cross section of any shape. Intermediate elements **406** can have essentially the same mechanical and acoustical properties as intermediate elements **306**, and therefore may have the same composition, except for the lack of the conducting particles in intermediate elements **406**. Because intermediate elements **406** may have a lower resistance, intermediate elements **406** may be made taller than intermediate elements **306**. The mechanical properties of intermediate layer **406** may also be slightly different.

[0062] Conductor **408** and the bonding material (such as adhesives, solders, and welding material) should not cause acoustic reflections or perturbations. To avoid acoustic reflections or perturbations, the thickness and size of perturbing items within the acoustic path may be small compared to the acoustic wavelengths of interest. Conductor **408** should adhere to the insulating media well enough to retain the structure's mechanical. The insulating media used for intermediate elements **406** should have adequate acoustical attenuation to avoid sound reflections from connector **208** of signal generating and receiving unit **210** that would otherwise reach acoustic transducing element **312**. The insulating media used for intermediate elements **406** should have suitable acoustic impedance for optimum performance. The insulating media of intermediate elements **406** may provide mechanical integrity and positioning accuracy of acoustic transducing element **312** and connector **208** of the signal generating and receiving unit **210**.

[0063] **FIGS. 5 and 6** are the same as **FIG. 4** except that the **FIGS. 5 and 6** embodiments include optional adhesive **320**. Also, in the **FIG. 5** embodiment conductor **408** is exposed, while in the **FIG. 6** embodiment, conductor **408** is covered. with optional film **412**.

[0064] **FIG. 7** is another embodiment **700** having a coating of an insulative coating **702** made from Kapton®, or Mylar®, for example, on any number of sides greater than two including both ends, and having conductor **408** laminated thereon. The intermediate elements **704** can be the same as intermediate elements **406**, or can be a conductor.

[0065] **FIG. 8** is another embodiment **800**, which is the same as that of embodiment **700** of **FIG. 7**, except that an optional film **412** covers the exposed portion of conductor **408** and is intermediate conductor **408** and optional filler **318**.

[0066] Although **FIGS. 6-8** show optional adhesive **320**, it does not need to be present.

[0067] **FIGS. 9 and 10** are the same as **FIGS. 7 and 8**, respectively, except that intermediate element **902** and optional film **1002** do not extend all the way down to conductive pads **410***a*, leaving a gap. The gap may be filled with optional filler **318**. If optional filler **318** is not used, the couplings to electrical pads **304** will remain flexible, thereby providing vibration isolation. If optional filler **318** is used, it provides mechanical integrity and holds the intermediate elements in place. The couplings to the rows and/or columns of electrical pads can be done at any stage of the construction of the interconnection-backing media, or after its completion. Intermediate elements **902** may be posts and can have a cross section of any shape. Intermediate elements **902** can have essentially the same mechanical and acoustical properties as intermediate elements **406** except that since intermediate elements **902** do not extend to conductive pads **410***a*, the mechanical properties can be slightly different.

[0068] Although **FIGS. 9 and 10** do not show optional adhesive **320**, it could be included.

[0069] **FIGS. 11A** and B show flow charts of methods **1100***a* and **1100***b*, respectively, of using an embodiment of the invention. **FIG. 11A** is a method of transmitting acoustic signals, and **FIG. 11B** is a method of receiving acoustic signals.

[0070] Referring to **FIG. 11A**, in step **1102** the signal generating and receiving unit **210** generates an electrical signal. In step **1104**, the electrical signal is cablelessly coupled via connector **208** and through a possible connector (not shown) and electrical pads **304** to intermediate structure

204. In step **1106**, the electrical signal is coupled through intermediate structure **204** to acoustic transducing element **312**. In step **1108**, acoustic transducing element **312** generates an acoustic signal that is then transmitted via acoustical matching element **314** through optional acoustic window **316**.

[0071] Referring to **FIG. 11B**, the ultrasonic signals from step **1108** (**FIG. 11A**) are modified (e.g., reflected and/or transmitted) by the media of interest. In step **1122**, the modified ultrasonic signals are received. Optionally the reception includes transmitting the ultrasonic signals through the optional acoustical window **316**, and receiving them via acoustic matching element **314** by typically a different combination of acoustic transducing elements **312** because the direction of the incident and reflected ultrasound signals is typically different. However, in an embodiment each acoustic transducing element **312** can be used both for receiving and transmitting the modified ultrasonic signal. In another embodiment each acoustic transducing elements **312** may be grouped into pixels having a receiving half and a transmitting half. The acoustic transducing elements **312** convert the ultrasonic signal into an electrical signal. In step **1124**, the electrical signals are sent through intermediate structure **204**. In step **1126**, the signals from intermediate structure **204** are sent via electrically conducting structure **206** through connector **208**. In step **1128**, the signals from connector **208** are sent back to signal generating and receiving unit **210** for processing to produce an image on a monitor or store as data for producing an image on a monitor. The receiving step may include attenuating reflections within the handheld ultrasound unit **200** such as with the use of optional filler **318** and acoustically the attenuating materials used in intermediate elements **306**, **406**, and **902**.

[0072] **FIGS. 12A** and B show a method **1200** of making an embodiment of the invention, and some of the temporary structures formed at various stages of the process. In step **1202**, signal generating and receiving unit is formed or provided, and connector **208** is coupled to or formed on signal generating and receiving unit **210**. The rest of signal generating and receiving unit **210** can be formed, assembled, or constructed at anytime relative to forming or coupling connector **208** on signal generating and receiving unit **210**. In step **1204** an electrically conductive layer **1220** could be deposited on connector **208** for forming electrical pads **304**. Also in step **1204**, an electrically conductive and acoustically attenuating media **1222** is laminated on an electrically conductive layer **1220**. Further in step **1206**, a first conductive layer **1224**, an acoustically active layer **1226** and a second conductive layer **1228** form an acoustic transducing sandwich **1230**. Acoustic transducing sandwich **1230** is bonded to electrically conductive and acoustically attenuating media **1222**. Acoustic transducing sandwich **1230** could be first constructed and then bonded to electrically conductive acoustically attenuating layer **1222**, or it could be laminated layer by layer directly upon electrically conductive and acoustically attenuating media **1222**. In step **1208**, an acoustic matching layer **1232** is bonded to one side of acoustic transducing sandwich **1230**. Acoustic matching layer **1232** may include multiple layers and/or have significant structure to improve acoustic matching. In step **1210**, material is removed from the composite structure leaving columns and forming the kerfs. A small amount of connector **208** may also be removed during step **1210** in order to be certain that all of the conductive material between electrical pads **304** is removed, and optional adhesive **320** may be added. In step **1212**, optional filler **318** is added to the kerfs and allowed to harden. In step **1214**, optional acoustic window **316** is bonded to acoustic matching element **314**. Optional acoustic window **316** may have ground sheet **315** formed on it by metallization or deposition for example before being secured to acoustic matching element **314**.

[0073] **FIGS. 13A** and B show a method **1300** of making an embodiment of the invention and some of the temporary structures formed at various stages of the process. In step **1202**, signal generating and receiving unit is formed or provided, and connector **208** is coupled to or formed on signal generating and receiving unit **210**, as in method **1200**. In step **1302**, electrically conductive and acoustically attenuating pillars that form intermediate elements **406** or **902** are attached to connector **208**. Although not shown in **FIG. 13B**, intermediate elements **406** or **902** are formed with conductor **408**, optional film **412** or **1002**, and insulative coating **702** attached thereto. Although also not shown in **FIG. 13B**, when intermediate elements **406** or **902** are attached to connector **208**, intermediate elements **406** or **902** are bonded to electrical pads **304** on connector **208**. Intermediate elements **406** or **902** with conductor **408**, optional film **412** or **1002**, and insulative coating **702** attached thereto may be formed as structures **1320** on a sheet **1322** so that they can be fixed in positions relative to one another and aligned with electrical pads **304**. Structures **1320** may be first formed and then attached to sheet **1322** or may be formed on sheet **1322**. The formation of structures **1320** is described in more detail in relation to **FIG. 14**, below. Alternatively, electrical pads **304** may be included in structures **1320**, for example. After bonding structures **1320**, to connector **208**, sheet **1322** is detached. In optional step **1304**, optional filler **318** may be added as a liquid and allowed to harden. In step **1206**, an acoustic transducing sandwich is bonded to intermediate structure **204**. The acoustic transducing sandwich includes a first conductive film, an acoustically active layer, and a second conductive film. The acoustic transducing sandwich could be first constructed and then bonded to the electrically conductive acoustically attenuating media, or could be laminated layer by layer directly upon the electrically conductive and acoustically attenuating media. Next in step **1206**, material is removed from the transducing sandwich to form acoustic transducing elements **312**. Alternatively, acoustic transducing elements **312** could also be formed on the same sheet **1322** while making the intermediate elements as part of structures **1320**. Method **1300** then proceeds as in method **1200** with steps **1208**, **1210**, **1212**, and **1214**. Method **1300** may include neither of or just one of steps **1304** and **1212**. Alternatively, part of the optional filler **318** may be added during step **1304** and part may be added during step **1212**.

[0074] **FIG. 14** shows a flowchart of method **1400** for making the intermediate elements of an embodiment of the invention. In step **1402** method **1400** starts with providing or forming intermediate elements **406** or **902**, which may be formed on sheet **1322** or formed separately and then attached to sheet **1322** after the completion of method **1400**. If structures **1320** (which form intermediate elements **406** or **902**) are formed on sheet **1322** a conductive layer (not shown) is first be deposited on sheet **1322** and then an insulative layer (not shown) is deposited from the composite structure leaving columns to form conductive pads **410*b*** attached to intermediate elements **406** or **902**. Conductive pads **410*b*** form a first part of conductor **408**. Some material from sheet **1322** may also be removed or alternatively the conductive layer (not shown) may be left exposed and not separated into conductive pads **410***b*. Optionally, in step **1404**, intermediate elements **406** are coated with an insulative coating **702** some of which may be removed to expose the conductive layer (not shown) or conductive pads **410***b*. In step **1406**, intermediate elements **406** are coated with conductor **408**. However, if structures **1320** were formed on sheet **1322** then the part of conductor **408** that forms conductive pad **410***b* will already be present. The conductor **408** may be attached to insulating coating **702** or embedded within insulating coating **702** first and then attached to intermediate elements **406** via insulative coating **702**. The conductive layer (not shown) is separated into conductive pads **410***b* if not already separated in step **1402**. In optional step **1408**, the conductor **408** is covered with optional film **412** or **1002**. Optional film **412** or **1002** provides an insulating and protective coating thereby embedding conductor **408** in the composite structure formed by intermediate elements **406** or **902** and optional film **412** or **1002**, respectively.

[**0075**] Although the word "structure" is used to describe many elements, these elements could also be assemblies, which in this Application is generic to the word "structure" but also includes assembles or collections of parts. The word "coupling" in this application is generic to direct connection and a connection made via an intermediate element as well as any other type of coupling, link or way of attaching elements together.

[**0076**] The invention could also be constructed using other signals, such as optical signals rather than electrical signals. In an optical embodiment electrically conducting structure **206** may be replaced with an optical connection, for example. Although the acoustic transducing elements **312** are depicted as having electrical contacts **308***a* and **308***b*, they are only necessary if electrical energy is used to excite the active acoustic elements **310**. If the active acoustic elements **310** are excited by other forms of energy such as by using electric magnetic waves or mechanical energy, the electrical contacts **308***a* and *b* may not be used or may be replaced by coupling contacts for securing the active acoustic element in place.

[**0077**] Although the invention has been described with reference to specific embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the true spirit and scope of the invention. In addition, modifications may be made without departing from the essential teachings of the invention.

What is claimed:

1. A method comprising:

providing a signal generating and receiving unit;

coupling an acoustically isolating assembly to the signal generating and receiving unit; and

coupling acoustic transducing elements to the acoustically isolating assembly.

2. The method of claim 2, wherein coupling the acoustic transducing elements comprises interposing an acoustically active material between two electrical contacts.

3. The method of claim 3, wherein coupling the acoustic transducing elements comprises:

coupling an acoustic matching assembly to one of the two electrical contacts; and

coupling an acoustic window to the acoustic matching assembly.

4. The method of claim 1, wherein the signal generating and receiving unit comprises a motherboard.

5. The method of claim 1 further comprising placing a filler material within kerfs formed by the acoustically isolating assembly.

6. The method of claim 1, wherein coupling the acoustically isolating assembly comprises coupling insulating posts to conductors for conducting electrical signals.

7. The method of claim 6, wherein the conductors are longer than and extend beyond the posts.

8. The method of claim 1, wherein the acoustically isolating assembly comprises posts of an electrically conductive and acoustically attenuating material.

9. The method of claim 8, wherein the posts are anisotropic conductors.

10. The method of claim 8, wherein the posts are isotropic conductors.

11. The method of claim 8, wherein coupling the acoustically isolating assembly further comprises:

coupling conductors to an insulative backing; and

coupling the insulative backing to the posts.

12. A method comprising:

providing a generating and receiving unit;

providing acoustic transducing elements, including:

interposing an acoustically active material between electrical contacts,

coupling an acoustic matching assembly to one of the electrical contacts, and

coupling an acoustic window to the acoustic matching assembly;

cablelessly coupling an acoustically isolating assembly to the generating and receiving unit and the acoustic transducing elements, the acoustically isolating assembly including:

an acoustically isolating structure having posts configured to be electrically conductive and acoustically attenuating; and

placing a filler material within kerfs formed by the acoustically isolating structure.

13. The method of claim 12, wherein the posts are anisotropic conductors.

14. The method of claim 12, wherein the posts are isotropic conductors.

15. The method of claim 12, wherein the acoustically isolating assembly comprises insulating posts having conductors for conducting electrical signals.

16. The method of claim 15, wherein the conductors are partially embedded within the posts.

17. The method of claim 15, wherein the conductors are attached to the outside of the posts.

18. The method of claim 15, wherein the conductors have an insulative backing that is coupled with the posts.

19. The method of claim 15, wherein the conductors are longer than and extend beyond the posts.

20. A method comprising:

processing signals using a signal generating and receiving unit;

transducing ultrasound using an ultrasound transducing assembly having acoustic transducing elements that include

an acoustically active material between two electrodes,

an acoustic matching assembly coupled to one of the two electrodes, and

an acoustic window coupled to the acoustic matching assembly;

communicating signals between the ultrasound transducing assembly and the signal generating and receiving unit via a cableless coupling, the cableless coupling including

an acoustically isolating assembly having at least posts that are electrically conductive and acoustically isolating; and

acoustically isolating the acoustic transducing elements using

the acoustically isolating assembly, and

a filler material that is placed within kerfs formed by the acoustically isolating structure.

* * * * *

patsnap

专利名称(译)	超声波无线耦合方法		
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[标]申请(专利权)人(译)	TARAKCI UMIT IMRAN Mir上 MCLAUGHLIN GLEN 十一旭峰		
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摘要(译)

一种超声成像装置，包括二维阵列的超声换能器，其无线耦合到信号产生和接收单元，例如母板。该耦合包括声学衰减和导电结构，其可以包括导电或绝缘的柱，其具有嵌入或安装在外表面上的导体。还可以存在高密度连接器，允许二维阵列与主板耦合和分离。