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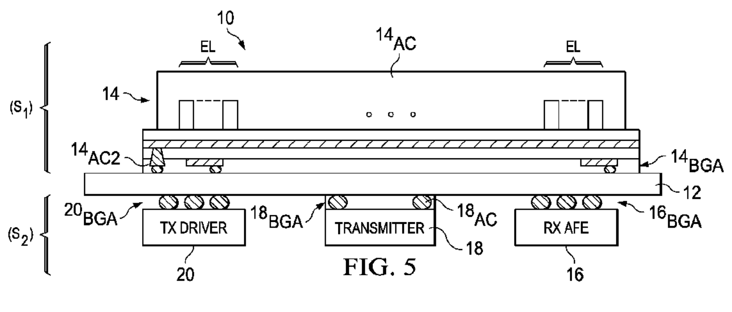

FIG. 5

(57) Abstract: In described examples, an ultrasonic transducer (10) has an interposer (12) having electrical connectivity contacts (14_{BGA}, 16_{BGA}). The ultrasonic transducer also has an ultrasonic receiver (14), including an array of receiving elements (MEM), physically fixed relative to the interposer and coupled to electrically communicate with electrical connectivity contacts of the interposer. The ultrasonic transducer also has at least one ultrasonic transmitter (18), separate from the ultrasonic receiver, physically fixed relative to the interposer and coupled to electrically communicate with electrical connectivity contacts of the interposer.

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EXTENDED RANGE ULTRASOUND TRANSDUCER

[0001[This relates generally to ultrasound transducers, and more particularly to combined discrete transmitter circuitry with a separate ultrasonic transducer receiver array.

BACKGROUND

[0002[Ultrasound transducers exist for transmitting ultrasound waves and detecting a reflection or echo of the transmitted wave. Such devices are also sometimes referred to as ultrasound or ultrasonic transducers or transceivers. Ultrasound transducers have myriad uses, including consumer devices, vehicle safety, and medical diagnostics. In these and other fields, signals detected by the transducer may be processed to determine distance which may be further combined with directional or area processing to determine shape and aspects in connection with two and three dimensional processing, including image processing.

[0003[A micromachined ultrasonic transducer (MUT) array is commonly used in conventional implementations as an ultrasound transducer to perform both the transmission of ultrasonic sounds and the detection of the sound echo. Such an array is typically formed using semiconductor processing, whereby an array of micromachined mechanical elements is created relative to the semiconductor substrate. Each array element has a same construction but is separately excitable to transmit a signal and separately readable to detect the signal echo. Various conventional techniques exist for forming numerous types of elements, where two common element examples are piezoelectric or capacitive, the former used for a so-called piezoelectric micromachined ultrasonic transducer (pMUT) and the latter used for a so-called capacitive micromachined ultrasonic transducer (cMUT). Generally, the pMUT array elements function in response to the known nature of piezoelectric materials combined sometimes with a thin film membrane, which collectively generate electricity from applied mechanical strain and, in a reversible process, generate a mechanical strain from applied electricity. Also, generally, the cMUT array elements function in response to the known nature of capacitive structure and in combination with an associated membrane, so the elements generate an alternating electrical signal from a change in capacitance caused by vibration of the membrane and, in a reversible process, generate vibration of the membrane from an applied alternating signal across the capacitor.

[0004[While the above and related approaches have served various needs, they also have various drawbacks. For example, acoustic power is a function of the product of pressure, area, and velocity, so the membrane used in a MUT may limit the transmission power because of limitations in sustaining pressure, a relatively small areal coverage on part of the transducer surface, and also due to reduced velocity form non-uniformities across the membrane. As another example, the number of elements in the MUT array are often increased to achieve greater resolution or other performance, and wire bonding or flex cable are often implemented for interconnectivity to each element, so a large number of elements (e.g., 50x50 or above) creates considerable complexity and cost in a wire bundle or cable to electrically communicate with all elements.

SUMMARY

[0005[In described examples, an ultrasonic transducer has an interposer having electrical connectivity contacts. The ultrasonic transducer also has an ultrasonic receiver, including an array of receiving elements, physically fixed relative to the interposer and coupled to electrically communicate with electrical connectivity contacts of the interposer. The ultrasonic transducer also has at least one ultrasonic transmitter, separate from the ultrasonic receiver, physically fixed relative to the interposer and coupled to electrically communicate with electrical connectivity contacts of the interposer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006[FIG. 1 illustrates an electrical block diagram of a first side of an ultrasound transducer per the preferred embodiments.

[0007[FIG. 2 illustrates an example, in cross-sectional view, of an element EL that may represent any of the various array elements in FIG. 1.

[0008[FIG. 3 illustrates an electrical block diagram of a second side of the ultrasound transducer of FIG. 1.

[0009[FIG. 4 illustrates a preferred embodiment transmitter.

[0010[FIG. 5 illustrates a cross-sectional view of an electrical block diagram of the ultrasound transducer of FIGS. 1 and 2.

[0011[FIG. 6 illustrates a cross-sectional view of a first alternative preferred embodiment ultrasound transducer.

[0012[FIG. 7 illustrates a cross-sectional view of a second alternative preferred embodiment ultrasound transducer.

[0013[FIG. 8 illustrates a cross-sectional view of a third alternative preferred embodiment ultrasound transducer.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0014[FIG. 1 illustrates an electrical block diagram of an ultrasound transducer 10 per the preferred embodiments. Various matters known in the transducer field may be used to supplement the block and functional description of this document. The preferred embodiments, therefore, are described with this understanding and with a concentration on the combination of certain technologies and layouts to achieve an overall ultrasound transducer device that provides advantages over conventional implementations.

[0015[Ultrasound transducer 10 is constructed to include an interposer (or carrier) 12 that provides a structural and electrical foundation for connection to various other devices that are part of the overall device. For example, interposer 12 may be a printed or other type of circuit board. With this understanding: (a) FIG. 1 illustrates a first side S_1 of interposer 12; (b) FIG. 3 illustrates a second side S_2, which is the opposite of side S_1, of interposer 12; and (c) FIG. 5 illustrates a partial cross-sectional view across interposer 12.

[0016[Referring again to FIG. 1, physically attached to side S_1 is an ultrasound receiver array 14, which may be constructed as various types of micromachined ultrasonic transducer receiver (MUT) arrays, known and further being developed. In conventional implementations, MUT arrays are commonly used both to transmit ultrasound waves and then detect their resultant echo; however, in the preferred embodiments, while using this same structure, array 14 is functionally used as an ultrasound receiver (*i.e.*, imager), whereas as discussed below different apparatus is used as an ultrasound transmitter. Array 14 as shown as being two-dimensional, having rows and columns of elements. For the illustrated embodiment, various elements are labeled with a coordinate shown as EL(row number, column number). As further detailed below, each element EL(*x*,*y*) provides a cavity, shown generally in FIG. 1 as a small square, where the cavity is surrounded by a material from which all the elements are formed; thus, array 14 may be formed by starting with a silicon member (e.g., square or circular) and forming the elements therein. Further, each element usually has a membrane along the bottom of the element cavity that will flex in response to response to receiving an ultrasound wave. In a preferred embodiment, the total number of row and column elements EL(*x*,*y*) are the same and equal to *x*+1, where preferably *x* is at least 7, and more preferably *x* is 49 or greater. Moreover, in an alternative embodiment, the number of row elements could differ from the number of column elements. In still another alternative embodiment, array 14 could be linear, whereby its elements are aligned in a single line. And in still another alternative embodiment, array 14 could be annular. Array 14 also may be constructed using various MUT technologies. One example embodiment uses a piezoelectric micromachined ultrasonic transducer (pMUT) as array 14. An alternatively preferred embodiment uses a capacitive micromachined ultrasonic transducer (cMUT), although a tradeoff is expected to include a higher cost of manufacturing. Either pMUT or cMUT may be constructed relative to a (*e.g.*, silicon) wafer using known and developed semiconductor and micromachining fabrication technologies, so that the elements are formed in part from the wafer material, as further described below.

[0017[In one preferred embodiment, array elements are formed in connection with a semiconductor wafer, with a partial illustration shown in FIG. 2. Specifically, FIG. 2 illustrates an example, in cross-sectional view, of an element EL that may represent any of the various elements in of array 14 in FIG. 1. Element EL includes a semiconductor surrounding a cavity in three-dimensional space, so the cross-sectional view of FIG. 2 illustrates this as two semiconductor sidewall members MEM_{SW} along with a rear wall member MEM_{RW} shown by and below a dashed line; in the illustrated cross-section, the front wall that otherwise would complete the surround around the element is not visible, but is further included, as also visible in FIG. 1. In any event, all such members MEM may be formed or result, such as by directionally etching from a surface of a semiconductor substrate or wafer, thereby creating respective cavities enclosed by surrounding semiconductor material, referred to herein as sidewall, front wall, and rear wall members for sake of reference. The members MEM are therefore the height of the original semiconductor substrate, with a usual contemporary example being 400 microns. Further therefore, with such a structure, preferably the cavities of each element are generally of the same size and shape. The design of cavity dimensions for acoustic performance is known. An element membrane EL_{MEM} is a layer adjacent one end of all the members and contiguous over the cavity. In a preferred embodiment, element membrane EL_{MEM} is in the range of 2 to 10 microns thick and extends across numerous different elements (*e.g.*, across the entire array). Therefore, the drawings are not to scale, as the element membrane EL_{MEM} is virtually indiscernible to view, as compared to the 400 microns or so of the members MEM. In any event, preferably, membrane EL_{MEM} is formed as an insulator (*e.g.*, silicon dioxide or silicon nitride), as such materials are common in semiconductor manufacturing. Another preferable attribute of element membrane EL_{MEM}, as achieved by the indicated insulator materials, is being inert to chemicals, where such insulators are inert to a variety of common chemicals. Membrane EL_{MEM} is a mechanical structural element that sustains pressure from fluids (*e.g.*, air) that transmit acoustic signals, so for each element, the pressure sustained in the cavity is received by the portion of membrane EL_{MEM} under the cavity.

[0018[Adjacent to element membrane EL_{MEM} is a conductive layer providing a first electrode EL_{ELEC1}, which is preferably a metal layer in the range of 0.1 to 1 micron thick. First electrode EL_{ELEC1} also is not illustrated to scale, relative to the members MEM. Electrode EL_{ELEC1} also preferably extends across numerous different elements (*e.g.*, across the entire array). Alternatively, each element can have a separate electrode EL_{ELEC1} that is electrically isolated from other elements.

[0019[Adjacent to first electrode EL_{ELEC1} is a piezoelectric film layer EL_{PZF}, which as its name suggest is a piezoelectric layer, and it is the range of 0.1 to 2 microns thick (also not shown to scale relative to members MEM). Piezoelectric film layer EL_{PZF} also preferably extends across numerous different elements (*e.g.*, across the entire array), but its flexure under the cavity of an individual element is represented by electrical signals to detect a measure of ultrasound wave receipt by that element. Alternatively, each element can have a disjoint piezoelectric film layer EL_{PZF} so to further isolate electrical signals generated between different elements.

[0020[Adjacent piezoelectric film layer EL_{PZF} is a conductive layer providing a second electrode EL_{ELEC2}, which is preferably a metal layer in the range of 0.1 to 1 micron thick (also not shown to scale relative to members MEM). Second electrode EL_{ELEC2} does not apply across multiple elements, but instead is sized to be less than the cavity for a given cell except for a portion of that electrode that extends beyond the width of the cavity to provide an interconnect, as further detailed below. For example, therefore, electrode EL_{ELEC2} may have dimensions in the range of 10% to 80% of the cavity area.

[0021[Finally, in one preferred embodiment, a first conductive contact EL_{CT1} may be a metal formed through an opening created in piezoelectric film layer EL_{PZF}, to reach a portion of first electrode EL_{ELEC1}, and a second and separate conductive contact EL_{CT2} is connected to EL_{ELEC2}. Thus, first conductive contact EL_{CT1} is provided to electrically communicate first electrode EL_{ELEC1} and a second conductive contact EL_{CT2} is provided to electrically communicate second electrode EL_{ELEC2}, as interconnects to an interposer, as detailed below. Electrodes EL_{ELEC1} and EL_{ELEC2} are capacitively coupled.

[0022[Given the preceding, in a preferred embodiment and as further discussed below, each element of array 14 is operable to receive an ultrasonic reflection and, due to its structure and materials, provide an electrical signal representative of the received reflection. Toward this end, the first electrode EL_{ELEC1} may be connected to a reference potential such as ground, and the voltage on second electrode EL_{ELEC2} of any element may be electrically sensed relative to the reference, with that difference representing the flexure of piezoelectric film layer EL_{PZF}, in response to receiving an ultrasonic wave. Thus, additional circuitry, described below, is connected to separately access each such element so that any combination of respective elements signals may be processed to further develop information from the received reflections.

[0023[As introduced above, FIG. 3 illustrates side S_2 of interposer 12. In a preferred embodiment, physically attached to side S_2 are three separate electrical and operational blocks, including a receive (RX) analog-front-end (AFE) 16, an ultrasonic transmitter 18, and a transmit (TX) driver 20. Each of these items is described below.

[0024[RX AFE 16 is preferably an integrated circuit and includes analog signal conditioning circuitry, such as operational amplifiers and filters that provide a configurable electronic functional block for interfacing the analog signals provided by elements in ultrasound receiver array 14 to an external (*e.g.*, digital) circuit, such as an outside processor (*e.g.*, microcontroller, digital signal processor, microprocessor). Thus, RX AFE 16 may couple electrical signals from any array element to an external processor for further processing and analysis.

[0025[Transmitter 18 includes the actuator for generating the ultrasonic sound waves, independent of, and apart from, receiver array 14. A MUT (such as may be implemented in receiver array 14) is used in some conventional implementations as a transmitter; however, in the preferred embodiments, the ultrasonic transmission functionality is provided by independent apparatus. In this regard, transmitter 18 may be constructed from various technologies, known or ascertainable. One preferred embodiment of transmitter 18 is shown in a perspective view in FIG. 4. In this example, transmitter 18 is a single element ultrasonic transmitter, preferably constructed using bulk piezoelectric ceramic; in this regard, FIG. 4 illustrates a transmitter with a generally circular cross-section and having a single plate piezoelectric element 18_{PE} made of piezoelectric ceramic, such as lead zirconate titanate (PZT) or single crystal lead magnesium niobate-lead titanate solid solution (PMN-PT), sandwiched by two electrodes to couple to electrical excitations. Optionally, adjacent the front and transmitting side of piezoelectric element 18_{PE} is an acoustic couplant layer 18_{AC}, and on the non- transmitting side of piezoelectric element 18_{PE} is backing layer 18_{BL}. An electrical difference is applied across piezoelectric element 18_{PE}, as shown generally in FIG. 4 with differing bias (*e.g.*, ground and a non-ground voltage, V) at differing positions of the element. In response to this bias, and the thickness and material of piezoelectric element 18_{PE}, an ultrasound wave is transmitted toward, and beyond, a face 18_F of transmitter 18. Thus, the preferred embodiment implements bulk ceramics for transmitting ultrasound waves, which thereby afford much greater power as compared to certain other types of transmitters, such as if a MUT were used for the transmitter. Specifically, a thicker bulk ceramic can sustain greater voltage and allow more electric power converted through strain energy, as compared to MUT technology.

[0026[Referring again to FIG. 3, TX driver 20 is included in the preferred embodiment inasmuch as the power and noise requirements are likely to differ as between the lower power needs of RX AFE 16 and the higher power needs of transmitter 18. In this regard, TX driver 20 is preferably an integrated circuit and includes circuitry that provides level shifting as between the lower power available for RX AFE 16 and the higher power needed for transmitter 18. Such level shifting may include control/regulation of current and voltage within a varying range of input voltages.

[0027[As also introduced above, FIG. 5 illustrates a cross-sectional view across interposer 12 and other items described above, where additional details are now observed. In a preferred embodiment, each of array 14, RX AFE 16, transmitter 18, and TX driver 20 is physical and electrically interconnected to interposer 12. In one preferred embodiment, each of these items is constructed using bumping metallization or other flip chip bumps such as solder or plated copper so that contacts, such as via miniature ball grid arrays (BGA), may be used to both physically and electrically connect each respective circuit to conductors on interposer 12. In this regard, array 14 is shown to have a respective BGA 14_{BGA} to connect to side S_1 of interposer 12 to electrodes of array 14, where as shown in FIG. 2 those electrodes include electrode EL_{ELEC1}, such as for grounding the entire array and electrode EL_{ELEC2} for each respective element. To simplify the drawing, such electrodes are not labeled in FIG. 5 (and conductive contact EL_{CT2} is not shown to simplify the drawing). Further, each of RX AFE 16, transmitter 18, and TX driver 20 has a respective BGA 16_{BGA}, 18_{BGAE}, and 20_{BGA} to connect to side S_2 of interposer 12. The relatively large number of elements of array 14 will give rise to a shorter pitch and greater connectivity density among BGA 14_{BGA}, as compared to that of arrays BGA 16_{BGA}, 18_{BGA}, and 20_{BGA}. For example, the former may be in the range of usually less than 250 microns, or less than 100 microns, or even less than 50 micron, while the latter is in the range of usually greater than 400 microns.

Moreover, preferably the BGA (or other connectors) between transmitter 18 and interposer 12 are positioned to be out of the path of the acoustic wave transmitted by transmitter 18, which in the orientation of FIG. 5 is upward. Transmitter 18 also may be electrically connected to interposer 12 with other package footprints, such as used in quad flat packages (QFP), quad flat no-leads packages (QFN), or other outline packages such small outline integrated circuit (SOIC), or through-hole connectors.

[0028[FIG. 5 also illustrates that an acoustic couplant layer (or multiple layers) 14_{AC1} is formed upward between and vertically beyond the substrate members (*i.e.*, in the cavities) of array 14, and an acoustic couplant layer (or multiple layers) 14_{AC2} is formed between interposer 12and array 14. Similarly an acoustic couplant layer (or multiple layers) 18_{AC} is formed along transmitter 18 and more specifically on the transmitter surface that faces interposer 12 (recall, such an acoustic couplant layer 18_{AC} is also shown in FIG. 4). Each acoustic couplant layer may be formed by flowing the couplant during a dispense step, while then curing the layer to the positions shown. Each such acoustic couplant provides an acoustic matching layer to more readily communicate ultrasonic sounds and sensitivity from the structure to the medium in which transducer 10 is located. Accordingly, acoustic couplant layer 18_{AC} facilitates the transmission of ultrasonic waves from transmitter 18 in the direction of interposer 12, through array 14, and upward in the perspective of FIG. 5. Similarly, acoustic couplant layer 14_{AC} will facilitate the receipt by array 14 of the reflected echo of waves transmitted by transmitter 18. Further, in this regard, array 14 as a pMUT receiver has an additional benefit that both sides of the silicon receiver can serve as a sound port and receive acoustic signals; in contrast, if array 14 is implemented as a cMUT receiver, then preferably it further includes “through silicon via” (TSV) construction to send electric signals from the front side imager to the backside interconnect.

[0029[Given the preceding, the general operation of transducer 10 should be readily understood. Generally, an enabled power supply (*e.g.*, battery, not shown) is provided to transducer 10, and in response TX driver 20 applies sufficient level adjusting to drive transmitter 18 with relatively high power. Transmitter 18 then emits ultrasonic waves, such as sound or other vibrations at an ultrasonic frequency, and such emissions are optimized by acoustic couplant 18_{AC}, in the direction to and through interposer 12 and through and beyond array 14. After the passage of a time window for receiving an expected response, receiver array 14, lower-powered yet more resolution-sensitive relative to single-element transmitter 18, receives an echo of the transmitted signal, and the piezoelectric (or capacitive) nature of array 14 converts those echoes into proportional electrical signals. These element signals are then conditioned by RX AFE 16 for further processing, either by circuitry also on interposer 12 or connected via an interface of RX AFE 16.

[0030[Given the preferred embodiment construction and operation, various benefits are realized. For example, the use of an array 14 for receiving permits design adjustments for size and pitch determined by resolution needs to optimize sensing, while the use of one or more single-element transmitter 18 (as described below) will be sufficient in various applications for focus and/or synthetic aperture transmissions and may be further optimized for transmitting. Thus, each of array 14 and transmitter 18 may be independently optimized to adjust its own respective function, with little or no effect on the opposite function of the other. Moreover, the apparatus therefore requires only a relatively higher voltage signal path for the transmitter(s) apparatus/functionality, while a low voltage signal path is sufficient for the receiver apparatus/functionality. As further shown below, additional benefits may be realized in various alternative preferred embodiments.

[0031[FIG. 6 illustrates a cross-sectional view of an alternative preferred embodiment ultrasound transducer 10_{A1}. Transducer 10_{A1} generally shares much of the same construction and functionality as transducer 10 described above, with the difference that transducer 10_{A1} includes transmitters, shown in FIG. 4 as preferably three such transmitters, namely, transmitters 18.1, 18.2, and 18.3. Each transmitter 18.*x* is physically and electrically connected to side S_2 of interposer 12, in a manner comparable to transmitter 18 for transducer 10. Further, each transmitter 18.*x* in FIG. 4 is preferably a single element transmitter, having a respective acoustic couplant layer 18_{AC} along it and facing interposer 12, and electrically each transmitter is connected to interposer 12 via a respective BGA or other formats (not expressly numbered in the Figure).

[0032[Generally, the operation and functionality of transducer 10_{A1} is comparable to transducer 10, whereby each transmitter 18.*x* emits ultrasonic waves in the direction of its respective acoustic couplant, through interposer 12 and into the desired medium; such waves may be reflected by a nearby object, with the echo received and sensed by array 14. Also, however, TX driver 20 (or related circuitry) is operable to excite any or transmitter 18.*x* with controlled phase delay with respect to the other transmitter(s) for beam steering. The echo of such transmissions, as received by array 14, and with signals therefrom communicated via RX AFE 16, may be processed to determine some measure of directionality as a result of beam steering, rather than having a singular direction of emission/detection as in the case of a single transmitter.

[0033[FIG. 7 illustrates a cross-sectional view of an alternative preferred embodiment ultrasound transducer 10_{A2}. Transducer 10_{A2} generally shares much of the same construction and functionality as transducer 10 described above, with the difference that transducer 10_{A2} also includes transmitters, shown in FIG. 7 as preferably two such transmitters 18.1 and 18.2, and in addition each such transmitter 18.*x* is connected to side S_1 of interposer 12. Further in this regard, a respective acoustic couplant layer 18_{AC} is formed along a side of each of transmitters 18.1 and 18.2, but in FIG. 7 such layer is on the surface of the transmitter that is opposite of the surface that is electrically connected to interposer 12. Thus, in the perspective of FIG. 5, the lower surface of each transmitter 18.1 and 18.2 is connected, via a respective BGA, to interposer 12, while along the upper surface of each transmitter 18.1 and 18.2 is a respective acoustic couplant layer 18_{AC}.

[0034[Generally, the operation and functionality of transducer 10_{A2} is comparable to transducer 10_{A1}, whereby each transmitter 18.*x* emits ultrasonic waves in the direction of its respective acoustic couplant. However, such emissions for transducer 10_{A2} do not pass through interposer 12 (or array 14), so any signal dissipation that otherwise may be caused by such signal passage is avoided. Again, having multiple transmitters allow beam steering. The placement of the transmitters may be important for this purpose. Generally, transmitters may be placed at constant spacing for ease of use. However, for this reason, two closely packed transmitters may not offer much advantage. Accordingly, if many small transmitters are packed tightly, they tend to be smaller and would be limited in power output. In various preferred embodiments, therefore, and for transducer 10_{A2}, from wave mathematics, larger spacing between point sources allows finer angular resolution.

[0035[FIG. 8 illustrates a cross-sectional view of an alternative preferred embodiment ultrasound transducer 10_{A3}. Transducer 10_{A3} combines aspects illustrated and discussed above with respect to transducers 10_{A1} and 10_{A2}. Like transducer 10_{A1}, transducer 10_{A3} includes three transmitters 18.1, 18.2, and 18.3. However, a difference is that two of the transmitters in FIG. 8 are positioned on surface S_1, as was the case for transducer 10_{A2}, while the third transducer is positioned on surface S_2, as was the case for the transmitters in transducers 10 and 10_{A1}. Therefore, the operation of transducer 10_{A3} should be readily understood to combine aspects described above, with the additional directional resolution of three transmitters, while recognizing that some dissipation of the emission from transmitter 18.2 may occur as its emitted signal is directed through interposer 12 and array 14.

[0036[From the above, various preferred embodiments provide improvements to ultrasound transducers by providing such a transducer that combines discrete transmitter circuitry with a micromachined ultrasonic transducer receiver array. In contrast, conventional ultrasonic transducers seek to accomplish both transmission and imaging (sensing echo) with a same array, and usually greater sensitivity and resolution is sought by increasing the number of elements in such an array to a great degree. Such efforts increase complexity and cost. Moreover, the use of such arrays may tend to decrease range, given the physical limitations of thin films and small imager elements. In contrast, the preferred embodiments provide numerous benefits. For example, signal processing between transmission and detection can be re-optimized for best transmission beam forming and phase-array imaging. Further, with some AFE modification, in one mode of operation, the MUT can still be used for both receiving signals and transmissions, where for such short distances minimum transmission power is required and low voltage drive would be acceptably provided by RX AVE 16. Still further, discrete transmitters provide a high achievable transmitted power, while the array receiver provides a high achievable receiving resolution and integrated signal path. Moreover, the transmit and receive paths are decoupled, thereby providing improved signal integrity and optimized overall system sensitivity by handling transmission and sensing separately, namely, removing the need for transmission by the array to thereby provide the ability to maximize the array receiver sensitivity. Additionally, power is likewise separated, so that low voltage may be used with the array to reduce potential noise, maximize individual process capability, and improve potential on-chip coupling problems. Costs in the preferred embodiments are also well managed by implementing a low cost transmitter(s) without complicated machining and a smaller receiver than would be necessary as compared to one necessary to size up to transmit power. Still further, flip chip assembly provides a modest interconnect and assembly complexity. As a result of the preceding, the preferred embodiments may be implemented in numerous applications, such as: (i) high sensitivity finger print sensor; (ii) intra-vascular Ultrasound Sensor with photo acoustic TX or capability; (iii) ultrasound vein detector; or (iv) ultrasound commuted tomography (CT) or micro-CT, in which the TX element and RX element are not in the same transducer/location.

[0037[The preferred embodiments are thus demonstrated to provide an ultrasound transducer combining discrete transmitter circuitry with a separate ultrasonic transducer receiver array. The preferred embodiments have been shown to have numerous benefits, and still others will be further determined. Moreover, while various embodiments have been provided, adjustments are contemplated to various measures and architectures according to application and other considerations. For example, as mentioned earlier, one preferred embodiment may include array 14 as annular in shape; with the various illustrations of alternative transmitter locations, therefore, the annular array could include a transmitter(s) in the middle open area defined by the annulus and/or a transmitter(s) outside the perimeter of the annulus. In this manner, the various transmitters are useful to steer the beam in various x, y, z dimensions. As another example comparable in certain respects to an annulus with a singular open area, another preferred embodiment may include an array with multiple voids, such as areas where no semiconductor member wall material exists, and where each such void includes a respective transmitter. As yet another example, while illustrated preferred embodiments depict at least one ultrasonic transmitter and a separate ultrasonic receiver both physically connected to the interposer via their respective electrical contacts, in alternative preferred embodiments the physical connection may be separated from the electrical connection, and/or also may be facilitated by some intermediary structure, where in any event the transmitter is affixed, by some member or apparatus, physically relative to the interposer and also by the same or separate structure coupled to electrically communicate with electrical connectivity contacts of the interposer.

[0038[Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. An ultrasonic transducer, comprising:

an interposer having electrical connectivity contacts;

an ultrasonic receiver, including an array of receiving elements, physically fixed relative to the interposer and coupled to electrically communicate with electrical connectivity contacts of the interposer; and

at least one ultrasonic transmitter, separate from the ultrasonic receiver, physically fixed relative to the interposer and coupled to electrically communicate with electrical connectivity contacts of the interposer.

2. The ultrasonic transducer of claim 1, wherein the array includes at least 64 elements.

3. The ultrasonic transducer of claim 1, wherein the array includes a same number of rows and columns of the elements.

4. The ultrasonic transducer of claim 1, wherein the at least one ultrasonic transmitter includes a single element transmitter.

5. The ultrasonic transducer of claim 1, wherein the at least one ultrasonic transmitter includes a bulk ceramic transmitter.

6. The ultrasonic transducer of claim 1, wherein: the ultrasonic receiver is physically fixed adjacent a first side of the interposer; and the at least one ultrasonic transmitter is physically fixed adjacent a second side, opposite the first side, of the interposer.

7. The ultrasonic transducer of claim 6, further comprising a plurality of ultrasonic transmitters, including the at least one ultrasonic transmitter, wherein all of the plurality of ultrasonic transmitters are physically fixed adjacent the second side.

8. The ultrasonic transducer of claim 7, further comprising an acoustic couplant layer adjacent each transmitter and facing the interposer.

9. The ultrasonic transducer of claim 1, further comprising a plurality of ultrasonic transmitters, including the at least one ultrasonic transmitter.

10. The ultrasonic transducer of claim 9, wherein: the ultrasonic receiver is physically fixed adjacent a first side of the interposer; at least a first ultrasonic transmitter in the

plurality of ultrasonic transmitters is physically fixed adjacent the first side; and at least a second ultrasonic transmitter in the plurality of ultrasonic transmitters is physically fixed adjacent a second side, opposite the first side, of the interposer.

11. The ultrasonic transducer of claim 1, further comprising two ultrasonic transmitters, including the at least one ultrasonic transmitter.

12. The ultrasonic transducer of claim 1, further comprising three ultrasonic transmitters, including the at least one ultrasonic transmitter.

13. The ultrasonic transducer of claim 12, wherein: the ultrasonic receiver is physically fixed adjacent a first side of the interposer; a first ultrasonic transmitter and a second ultrasonic transmitter in the plurality of ultrasonic transmitters are physically fixed adjacent the first side; and a third ultrasonic transmitter in the plurality of ultrasonic transmitters is physically fixed adjacent a second side, opposite the first side, of the interposer.

14. The ultrasonic transducer of claim 1, wherein the ultrasonic receiver is physically fixed adjacent a first side of the interposer, and further comprising:

a plurality of ultrasonic transmitters, including the at least one ultrasonic transmitter, wherein all of the plurality of ultrasonic transmitters are physically fixed adjacent the first side.

15. The ultrasonic transducer of claim 1, wherein the ultrasonic receiver is physically fixed adjacent a first side of the interposer, and further comprising:

operational circuitry for operating at least one of the ultrasonic receiver and the at least one ultrasonic transmitter, the operational circuitry physically fixed adjacent a second side, opposite the first side, of the interposer.

16. The ultrasonic transducer of claim 15, wherein the operational circuitry includes analog front end circuitry for the ultrasonic receiver.

17. The ultrasonic transducer of claim 15, wherein the operational circuitry includes driver circuitry for providing a first voltage to the at least one ultrasonic transmitter, the first voltage being greater than a second voltage for operating the at least one ultrasonic receiver.

18. The ultrasonic transducer of claim 1, wherein the ultrasonic receiver includes a pMUT array.

19. The ultrasonic transducer of claim 1, wherein the ultrasonic receiver includes a cMUT array.

20. The ultrasonic transducer of claim 1, wherein the interposer includes: a first side with a first density of electrical connectivity contacts; and a second side with a second density of electrical connectivity contacts, differing from the first density.

21. The ultrasonic transducer of claim 1, wherein the at least one ultrasonic transmitter includes an annular shape.

22. The ultrasonic transducer of claim 21, wherein the annular shape has an open area within an outer annular region, and the at least one ultrasonic transmitter is fixed within the open area.

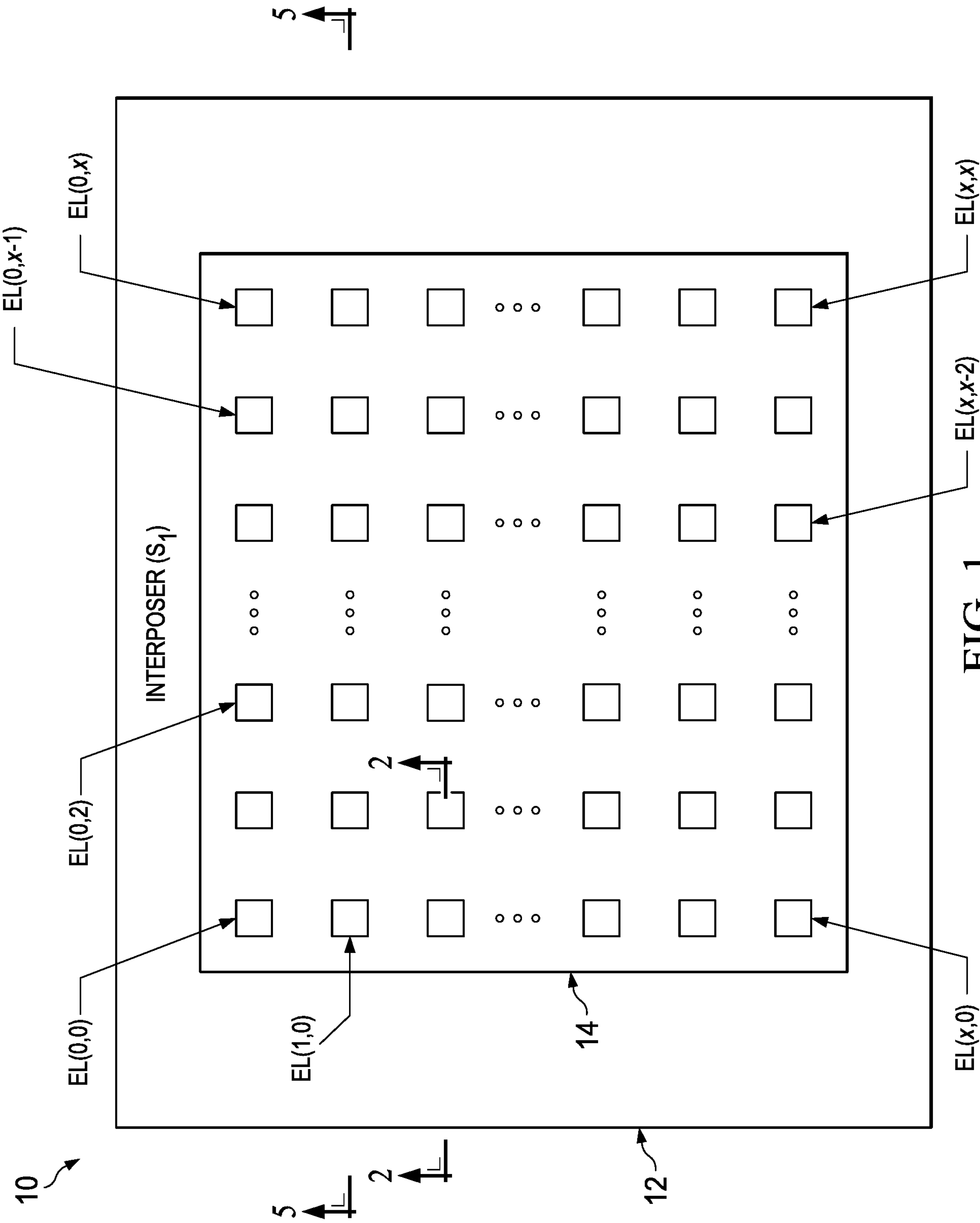
5
EL(0,x)
EL(0,x-1)
EL(x,x)
EL(x,x-2)
INTERPOSER (S_1)
EL(0,2)
2
EL(0,0)
EL(1,0)
14
EL(x,0)
10
2
5
12

FIG. 1

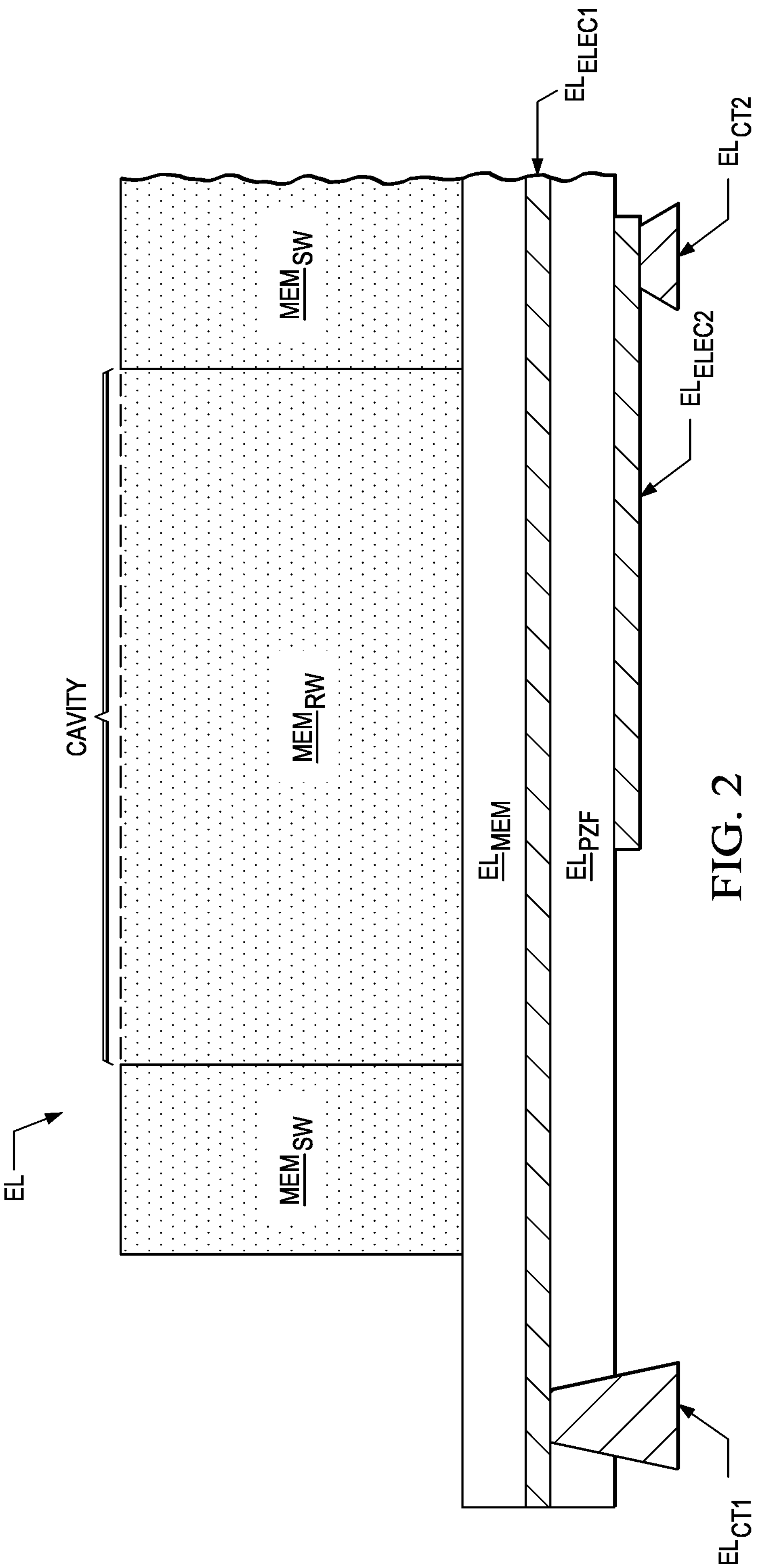
EL_{ELEC1}
EL_{CT2}
MEM_{SW}
EL_{ELEC2}
CAVITY
MEM_{RW}
EL_{MEM}
EL_{PZF}
MEM_{SW}
EL
EL_{CT1}

FIG. 2

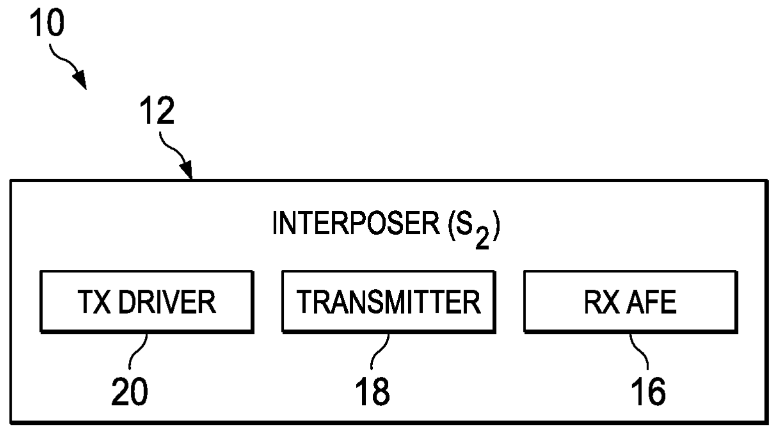
10
12
INTERPOSER (S_2)
TX DRIVER
TRANSMITTER
RX AFE
20
18
16

FIG. 3

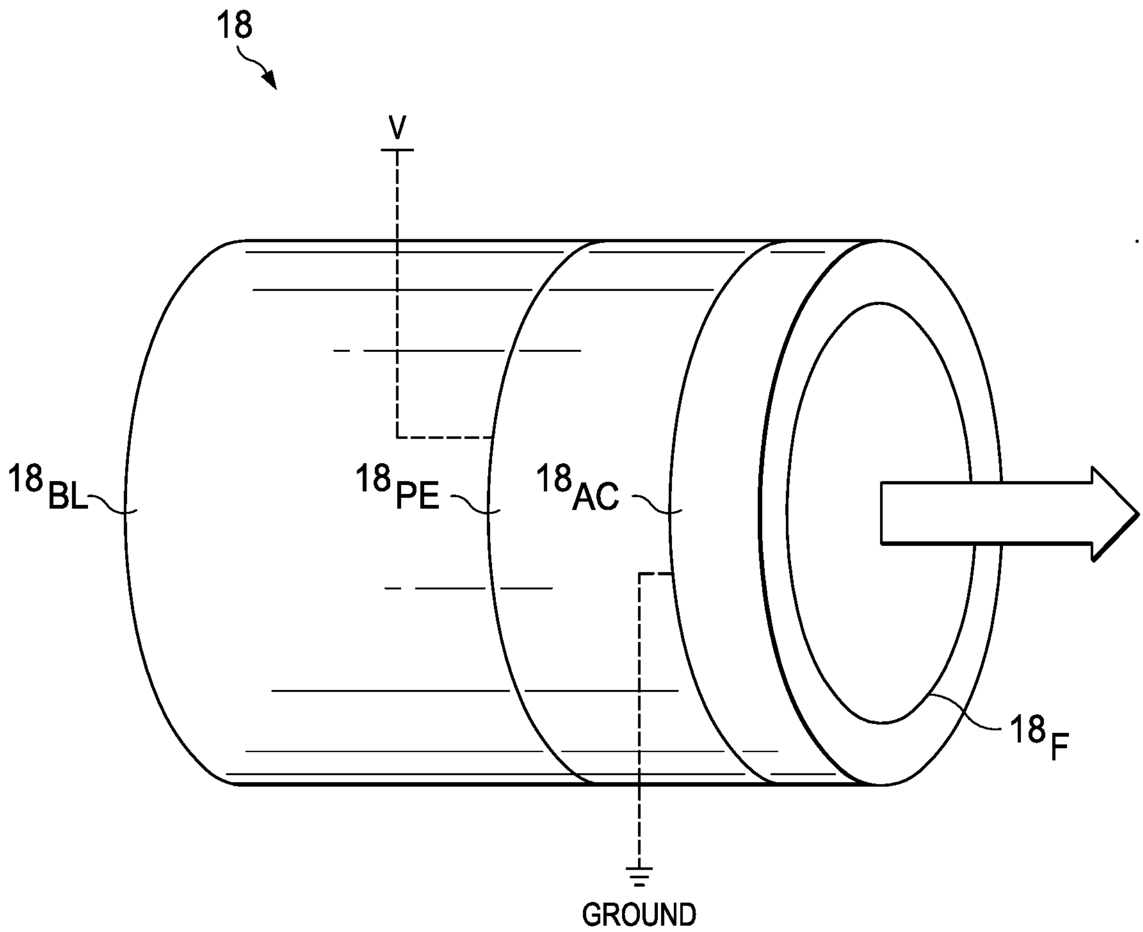
18
V
18_{BL}
18_{PE}
18_{AC}
18_F
GROUND

FIG. 4

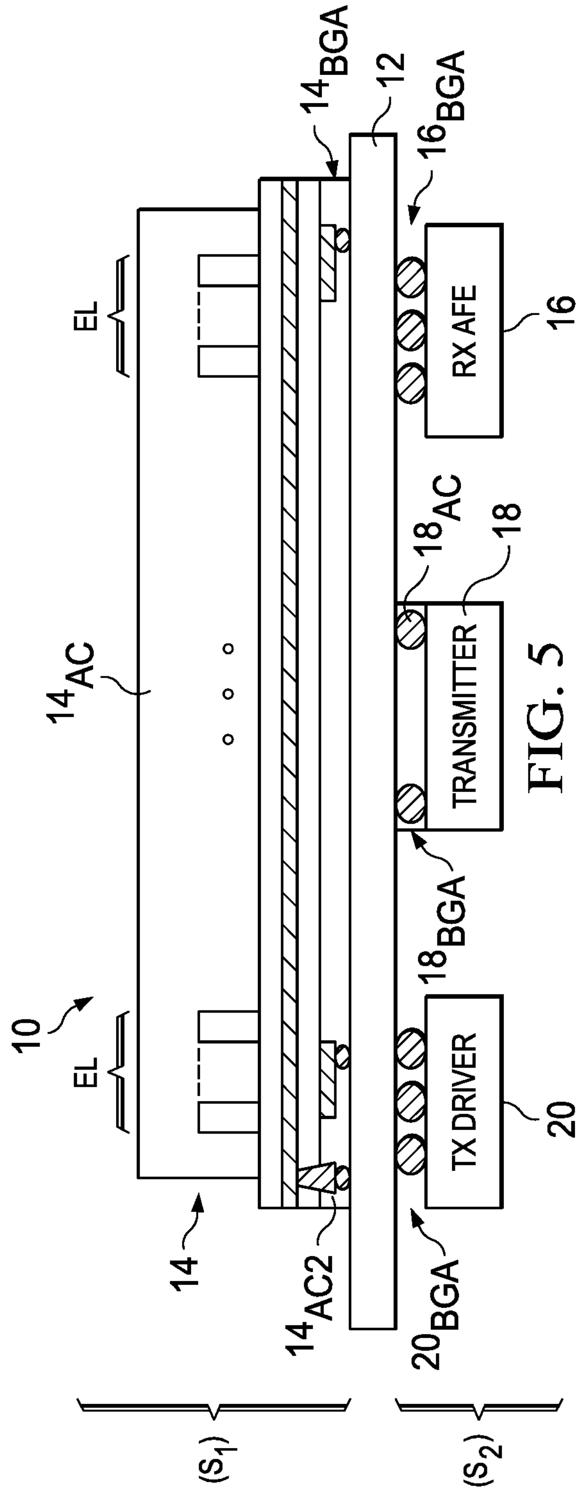
10
14
EL
14AC
EL
14BGA
12
16BGA
14AC2
20BGA
18BGA
18AC
18
TX DRIVER
20
TRANSMITTER
RX AFE
16
(S1)
(S2)

FIG. 5

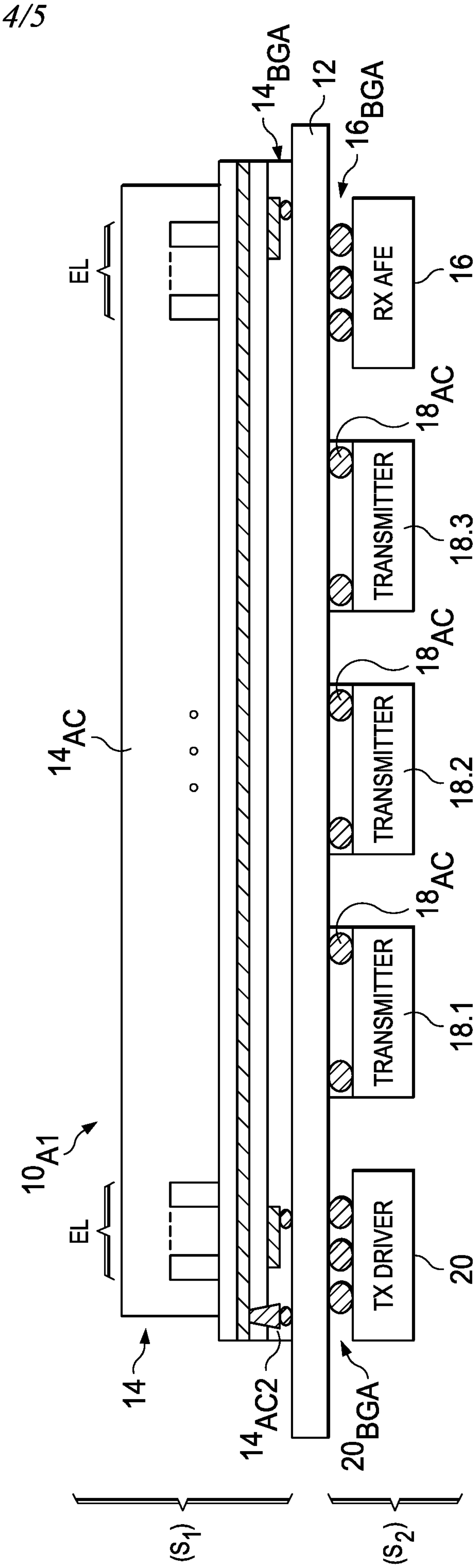
10A1
14
EL
14AC
EL
14BGA
12
16BGA
14AC2
20BGA
TX DRIVER
20
TRANSMITTER
18.1
18AC
TRANSMITTER
18.2
18AC
TRANSMITTER
18.3
18AC
RX AFE
16
(S1)
(S2)

FIG. 6

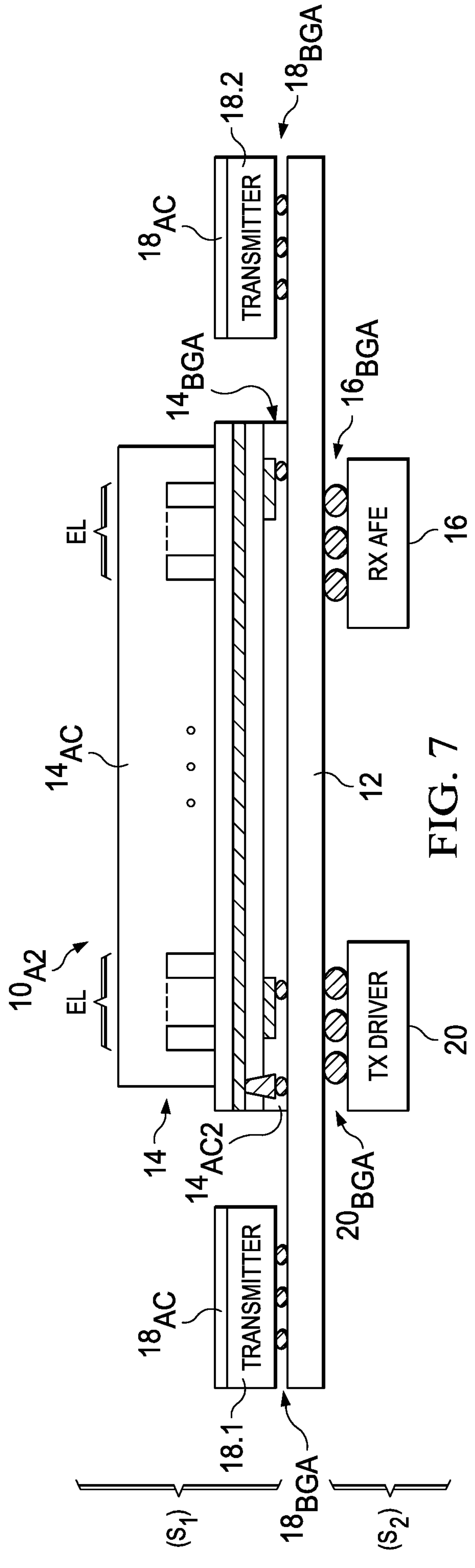
18BGA
18.2
18AC
TRANSMITTER
14BGA
16BGA
EL
RX AFE
16
14AC
12
10A2
TX DRIVER
20
14
14AC2
20BGA
18AC
TRANSMITTER
18.1
18BGA
(S1)
(S2)

FIG. 7

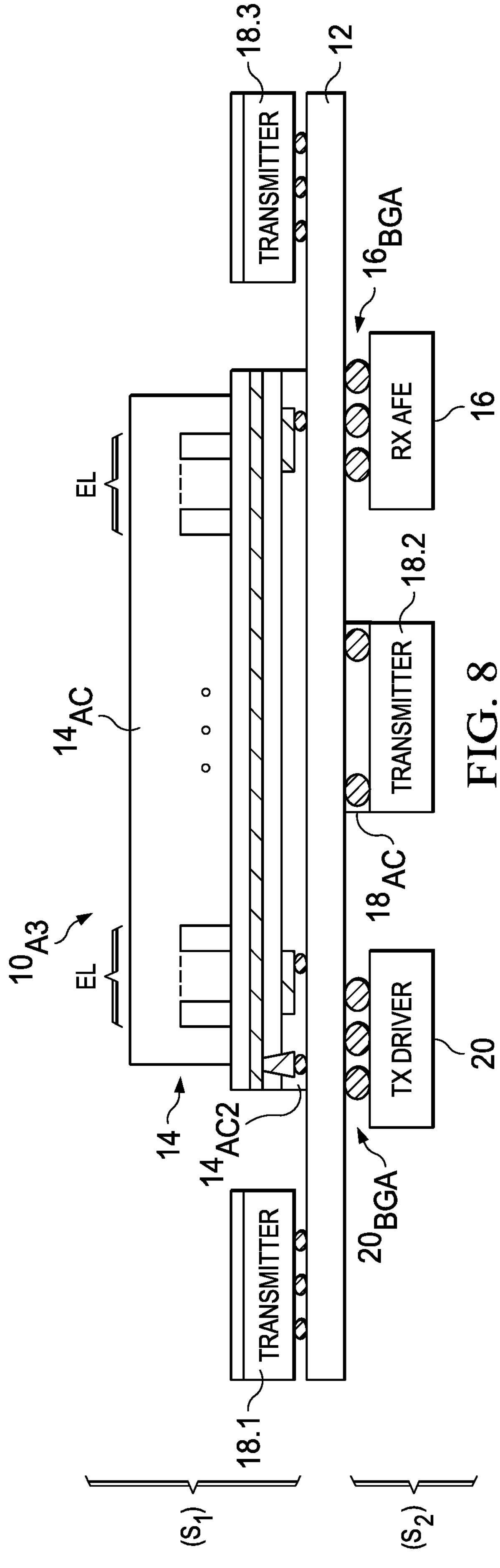
18.3
12
TRANSMITTER
16BGA
RX AFE
16
EL
18.2
TRANSMITTER
14AC
18AC
10A3
TX DRIVER
20
14
14AC2
20BGA
TRANSMITTER
18.1
(S1)
(S2)

FIG. 8

INTERNATIONAL SEARCH REPORT	International application No. PCT/US 2016/045055

A. CLASSIFICATION OF SUBJECT MATTER

B06B 1/02 *(2006.01)*
A61B 8/08 *(2006.01)*

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B60B 1/00-1/04, G01N 29/00, 29/04, 29/07, 29/11, 29/12, 29/22, 29/24, 29/34, A61B 8/00, 8/08, H04R 19/00, 17/00, H01L 41/00

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

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

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/0261467 A1 (RESEARCH TRIANGLE INSTITUTE) 03.10.2013	1-22
A	US 2012/0319535 A1 (RESEARCH TRIANGLE INSTITUTE) 20.12.2012	1-22
A	US 6865140 B2 (GENERAL ELECTRIC COMPANY) 08.03.2005	1-22
A	WO 2012/127360 A1 (KONINKLIJKE PHILIPS ELECTRONICS N.V.) 27.09.2012	1-22

☐ Further documents are listed in the continuation of Box C.　☐ See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 October 2016 (13.10.2016)	27 October 2016 (27.10.2016)
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37	Authorized officer E. Iritsky Telephone No. (499) 240-25-91

专利名称(译)	扩展范围超声换能器		
公开(公告)号	EP3328558A4	公开(公告)日	2018-08-01
申请号	EP2016833696	申请日	2016-08-01
[标]申请(专利权)人(译)	德州仪器公司		
申请(专利权)人(译)	得克萨斯仪器公司		
当前申请(专利权)人(译)	德州仪器公司		
[标]发明人	SHIH WEI YAN XU XIAOCHEN		
发明人	SHIH, WEI-YAN XU, XIAOCHEN		
IPC分类号	B06B1/02 A61B8/08		
CPC分类号	B06B1/0629 B06B1/0292 B06B1/0622		
代理机构(译)	ZELLER，ANDREAS		
优先权	14/814542 2015-07-31 US		
其他公开文献	EP3328558A1		
外部链接	Espacenet		

摘要(译)

超声波换能器。超声换能器具有插入器，该插入器具有电连接触点。超声换能器还具有超声接收器，该超声接收器包括接收元件阵列，所述接收元件阵列相对于插入器物理地固定并且被耦合以与插入器的电连接触点电连通。超声换能器还具有至少一个超声发射器，与超声接收器分开，相对于插入器物理固定并且耦合以与插入器的电连接触点电连通。