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(54) TRANSDUCER ADAPTERS FOR ALLOWING MULTIPLE MODES OF ULTRASOUND IMAGING USING A SINGLE ULTRASOUND TRANSDUCER

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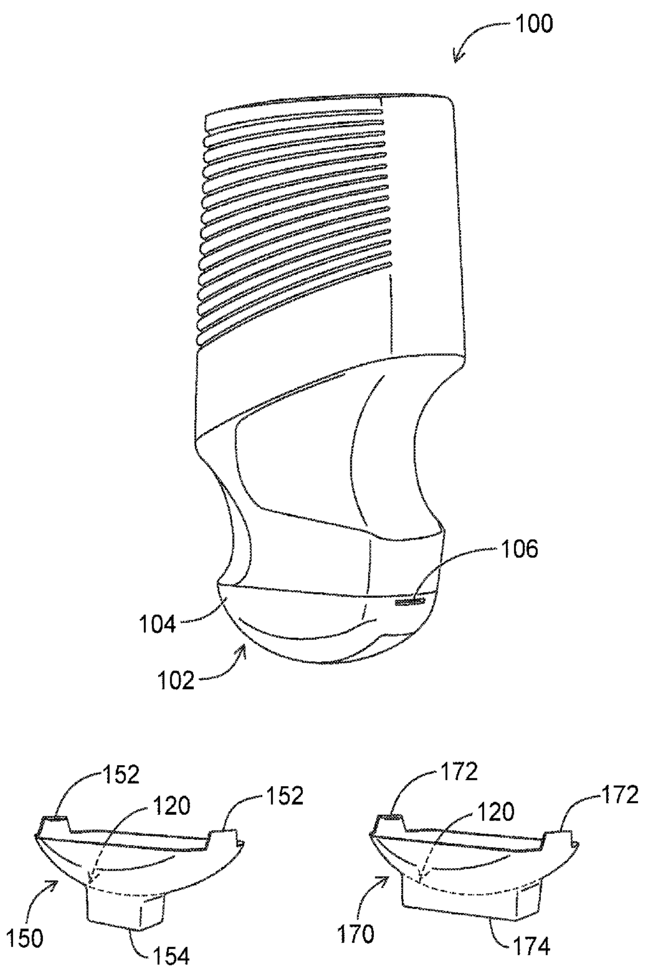
(57) **ABSTRACT**

The present embodiments relate generally to ultrasound imaging systems. The ultrasound imaging systems may include an ultrasound imaging transducer operable to acquire ultrasound image data and a transducer adapter configured to detachably couple to the ultrasound imaging transducer. The transducer adapter may provide a different footprint from the ultrasound imaging transducer native footprint to enable the ultrasound imaging transducer adapter to acquire ultrasound image data in a substantially similar way to ultrasound transducers with different transducer geometry. The ultrasound imaging transducer may include a sensor for detecting an attachment state of the transducer adapter. The ultrasound imaging transducer may modify one or more imaging parameters when the transducer is attached to the ultrasound imaging transducer.



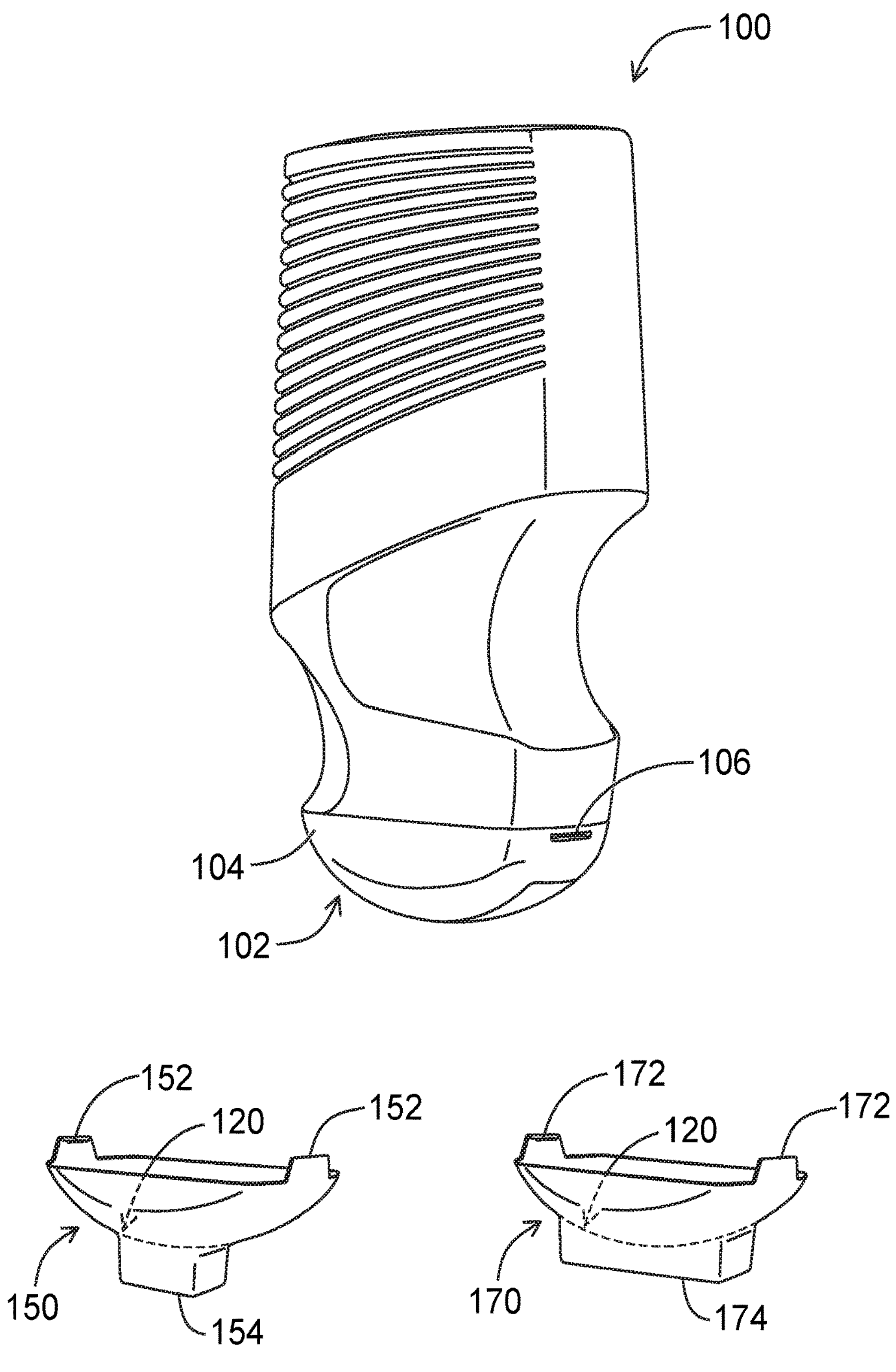


FIG. 1

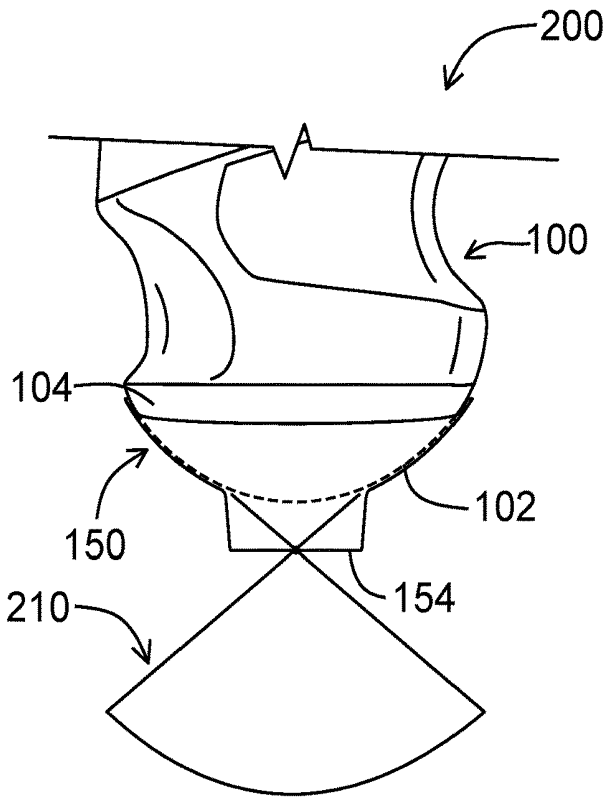


FIG. 2

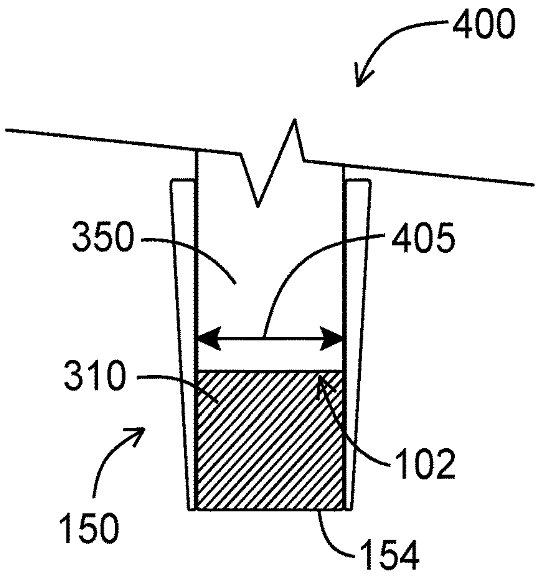


FIG. 4

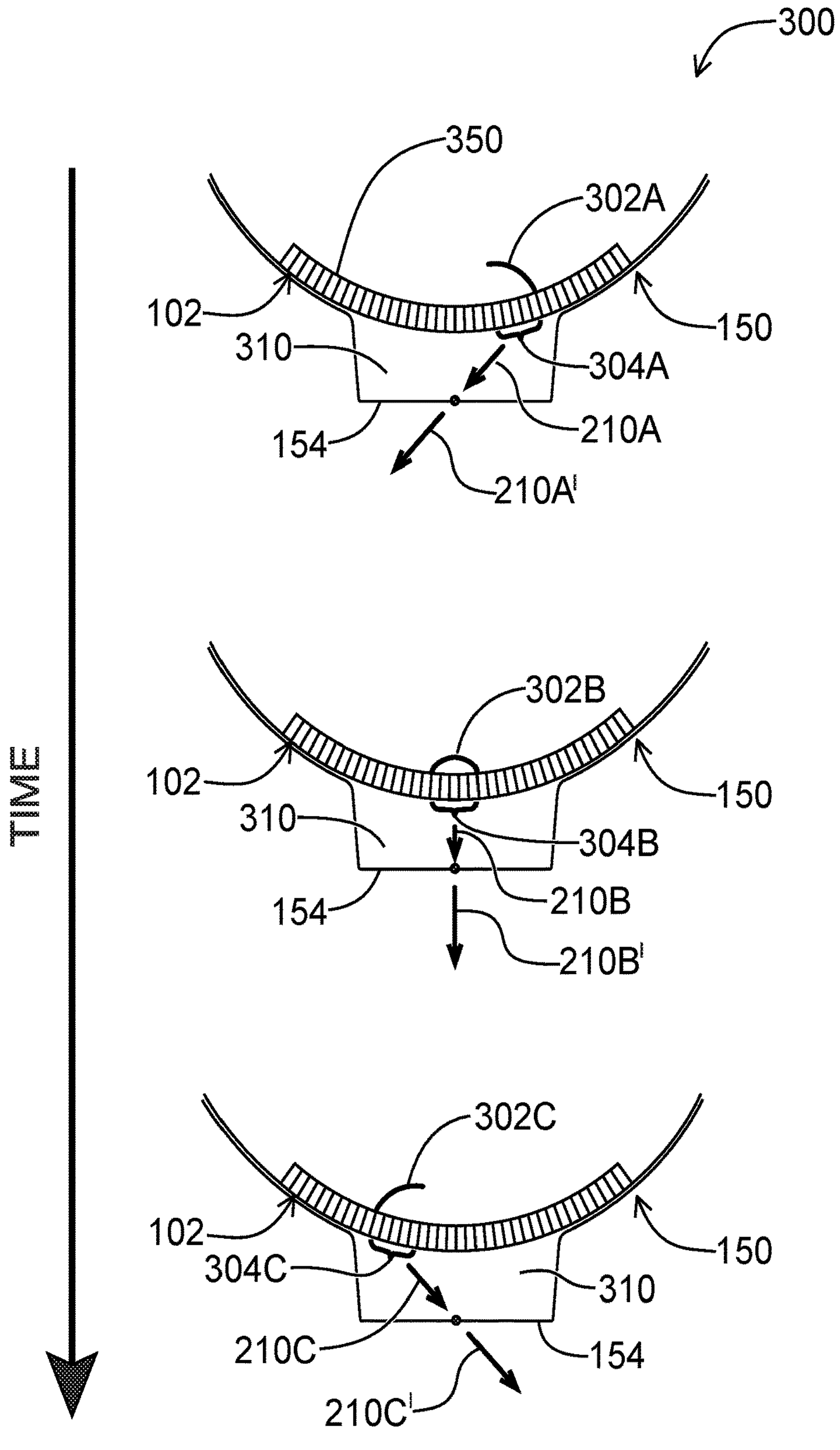

300
350
302A
102
150
310
304A
210A
154
210A'
302B
TIME
102
150
310
304B
154
210B
210B'
302C
102
150
304C
310
210C
154
210C'

FIG. 3

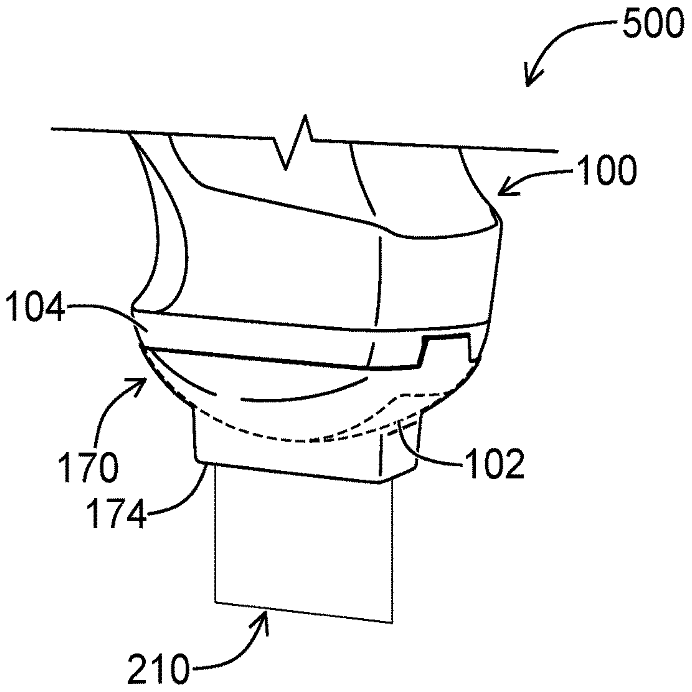


FIG. 5

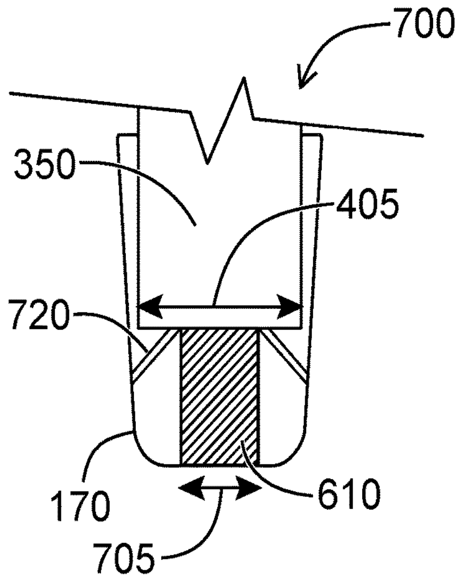


FIG. 7

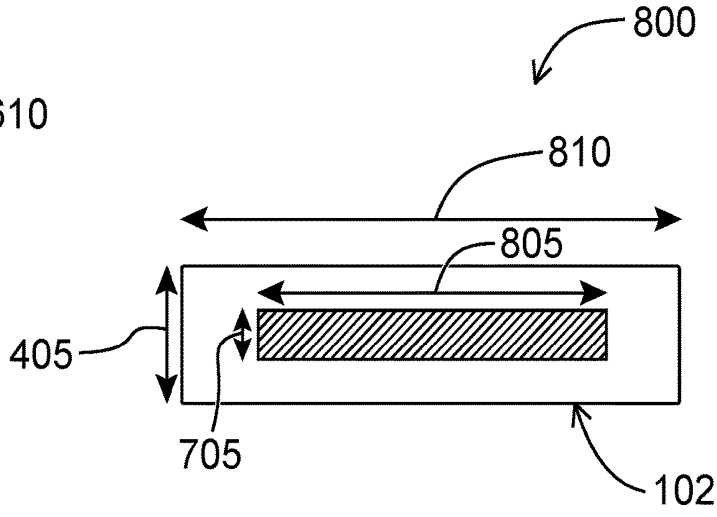


FIG. 8

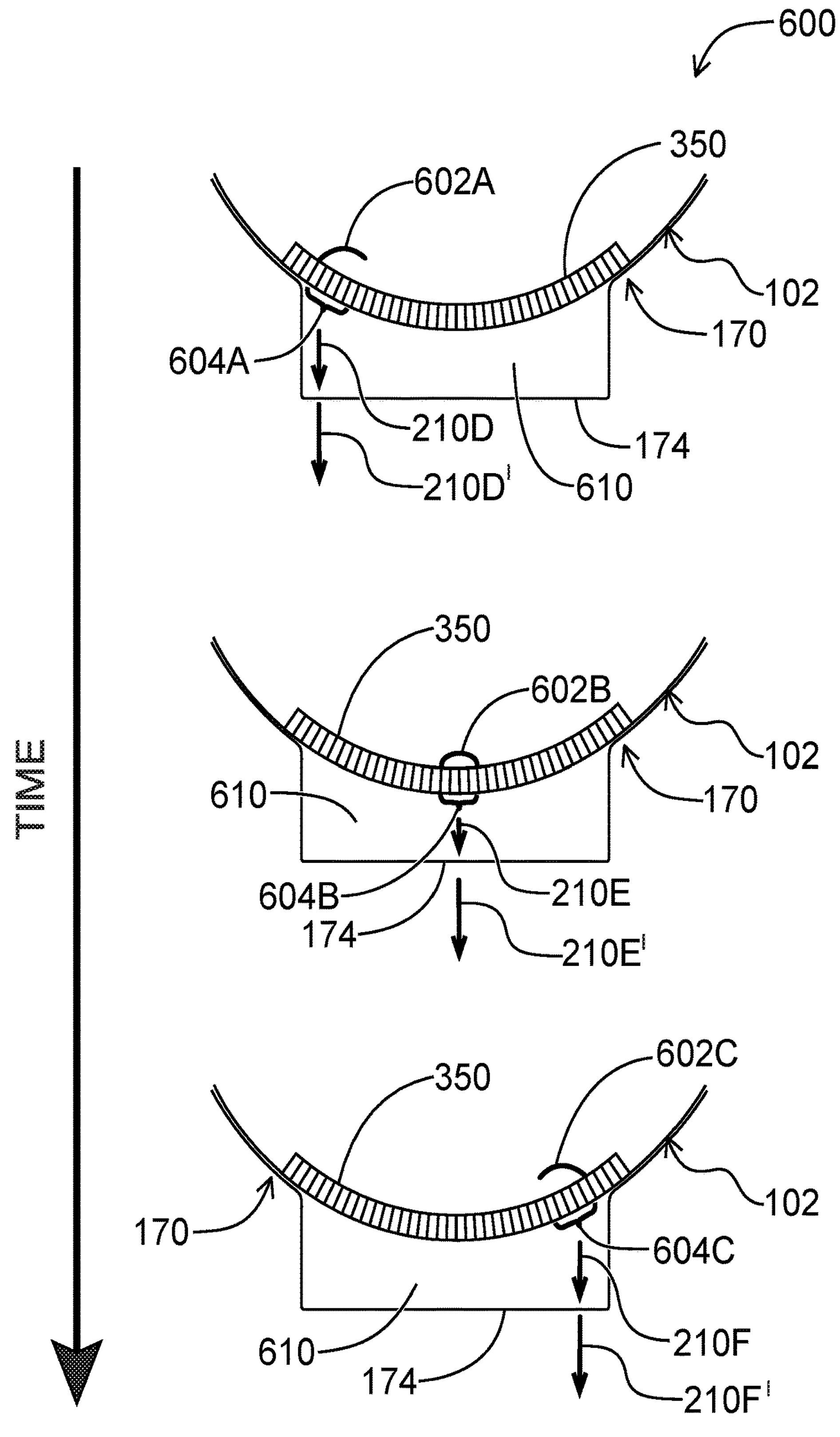
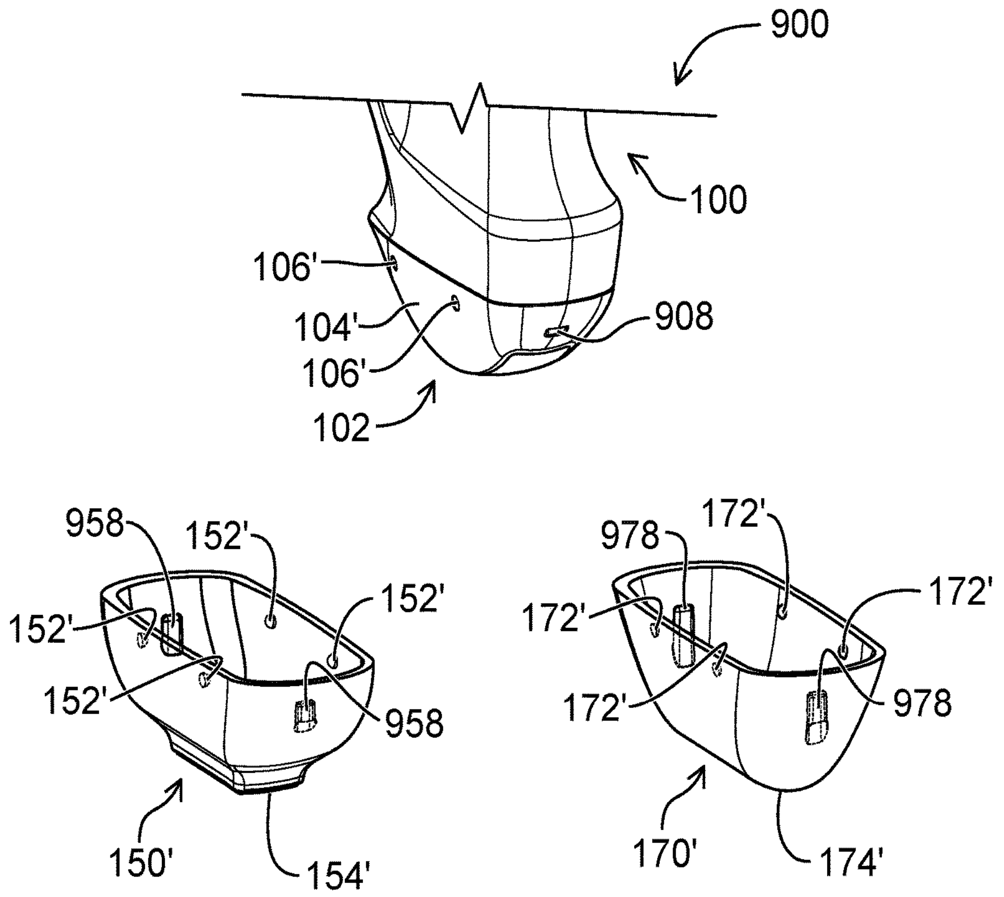

600
TIME
602A
350
102
170
604A
210D
174
210D'
610
350
602B
102
170
610
604B
210E
174
210E'
350
602C
102
170
604C
210F
610
174
210F'

FIG. 6


900
100
106'
104'
106'
908
102
958
152'
152'
152'
152'
958
150'
154'
978
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172'
172'
172'
978
170'
174'

FIG. 9

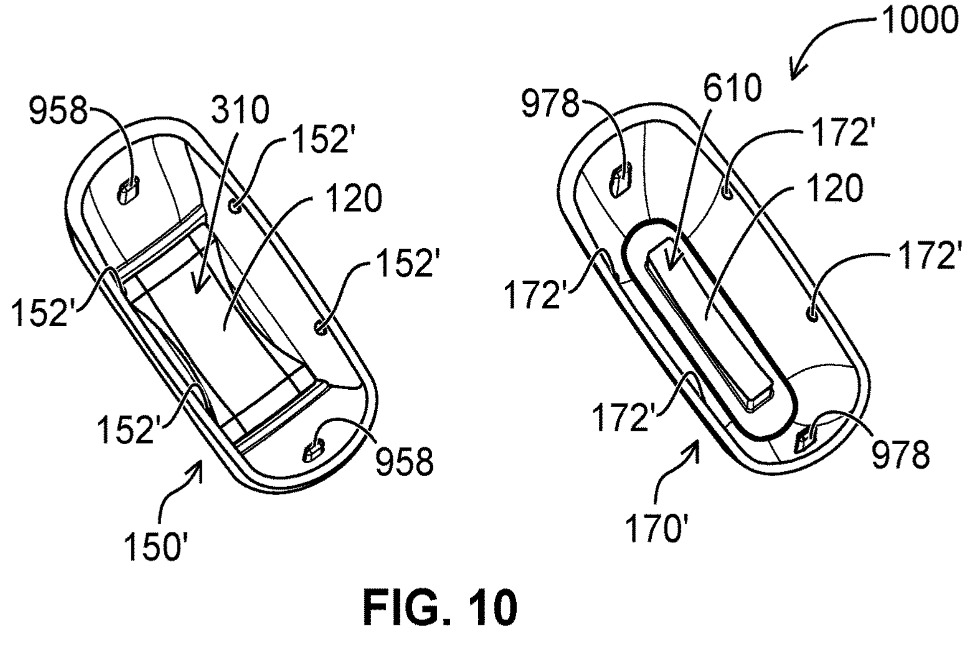
1000
958
310
152'
120
152'
152'
152'
958
150'
978
610
172'
120
172'
172'
172'
978
170'

FIG. 10

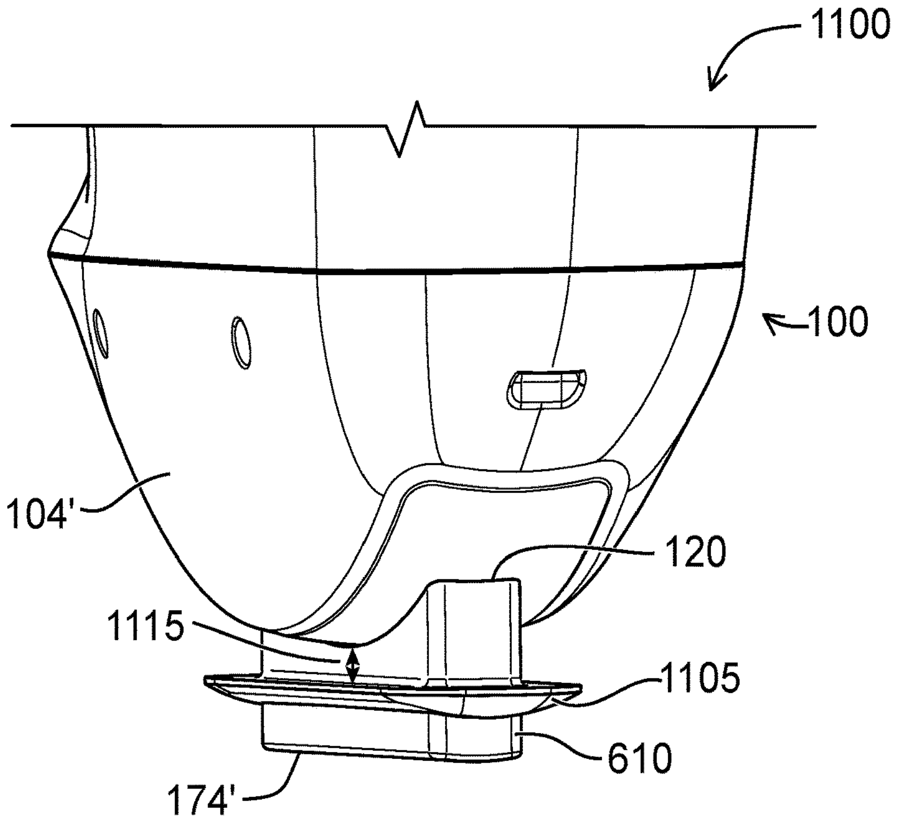
1100
100
104'
120
1115
1105
610
174'

FIG. 11

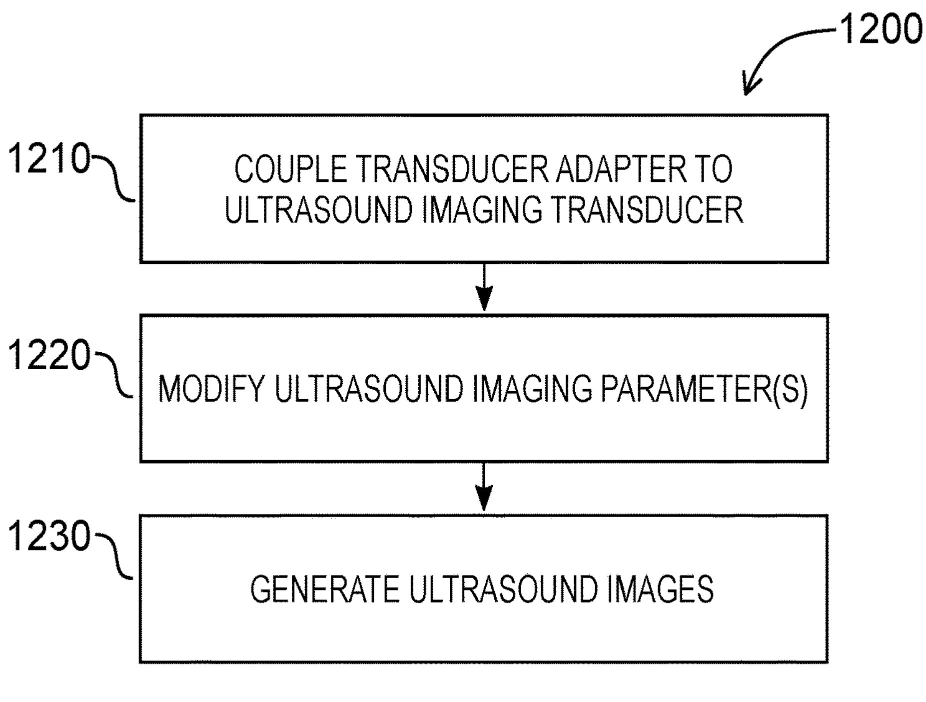
1200
1210
COUPLE TRANSDUCER ADAPTER TO ULTRASOUND IMAGING TRANSDUCER
1220
MODIFY ULTRASOUND IMAGING PARAMETER(S)
1230
GENERATE ULTRASOUND IMAGES

FIG. 12

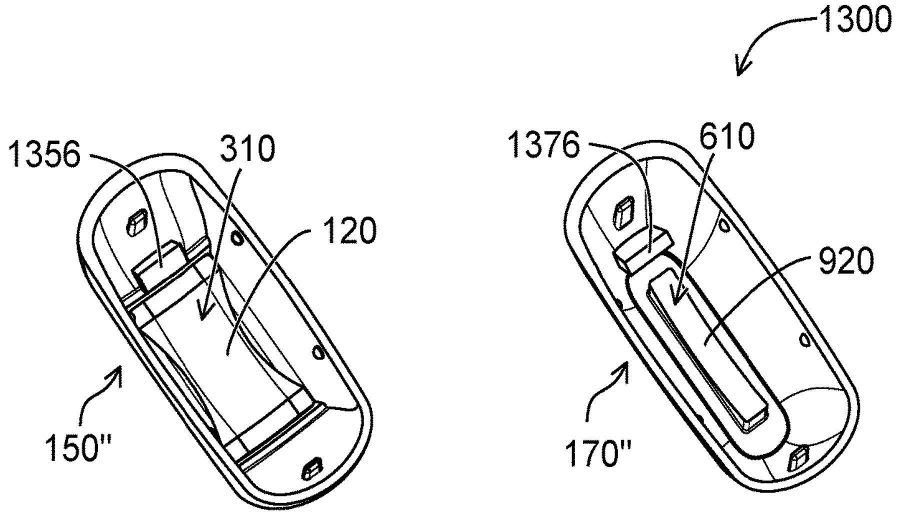
1300
1356
310
120
150''
1376
610
920
170''

FIG. 13

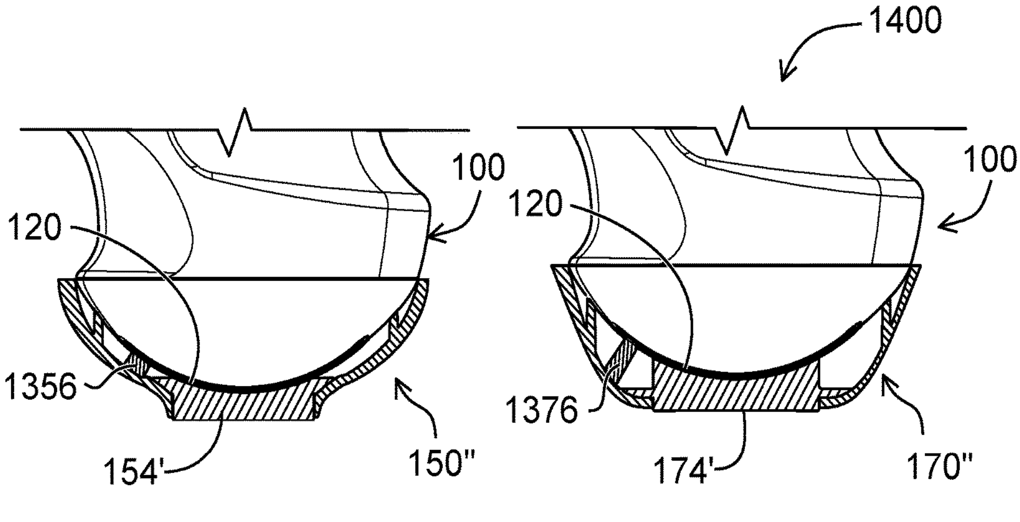
1400
100
120
1356
154'
150''
100
120
1376
174'
170''

FIG. 14

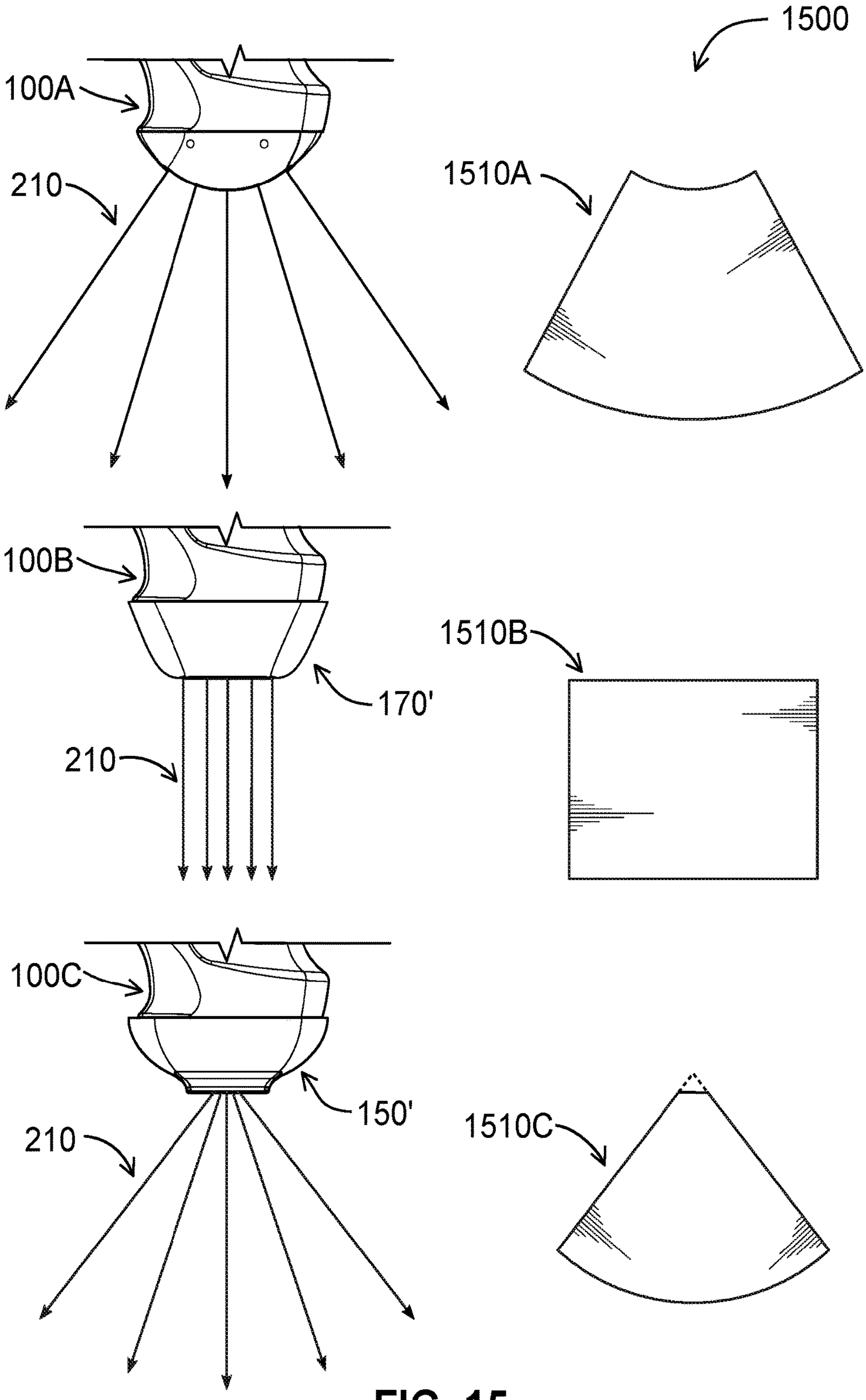

FIG. 15

TRANSDUCER ADAPTERS FOR ALLOWING MULTIPLE MODES OF ULTRASOUND IMAGING USING A SINGLE ULTRASOUND TRANSDUCER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/424,152 entitled "TRANSDUCER ADAPTERS FOR ALLOWING MULTIPLE MODES OF ULTRASOUND IMAGING USING A SINGLE ULTRASOUND TRANSDUCER" filed on Nov. 18, 2016, which is incorporated by reference it its entirety in this disclosure.

FIELD

[0002] The present disclosure relates generally to ultrasound imaging, and particularly, adapters for ultrasound transducers.

BACKGROUND

[0003] Traditional ultrasound systems are typically used with a number of different ultrasound probes that are designed to image different parts of the body. These different types of ultrasound probes have different transducer element configurations that make them suitable for imaging different parts of the body.

[0004] For example, a phased-array probe typically has a small footprint that allows the probe to be positioned on parts of the body that have constricted space (e.g., in the intercostal space in between a patient's ribs). Since imaging the heart is a common use for this type of probe, it is also called a cardiac probe.

[0005] In another example, a sequential curvilinear-array probe (also called a convex or curved probe) contains a larger footprint, with the transducer elements on the probe being positioned on a curve to provide a wide field of view. This configuration makes the curvilinear array probe suitable for imaging the abdomen.

[0006] In a further example, a sequential linear array probe may similarly have a wider footprint than that of a phased-array probe. Unlike a cardiac probe or a curvilinear probe, the linear probe directs parallel ultrasound signals from its linear transducer array so as to provide substantially similar lateral resolution in the near and far field. Linear array probes also typically have a shorter elevation length, so as to provide a finer slice thickness resolution.

[0007] Using different probes to examine different parts of the body is inconvenient. For example, in examinations performed in an emergency medicine context (e.g., during a Focused Assessment with Sonography in Trauma (FAST) examination), it is desirable to quickly examine multiple internal organs to arrive at a quick medical assessment. The time delay caused by the switching of probes may delay the performance of such examinations.

[0008] There is thus a need for improved methods and apparatus for imaging different areas of a patient using the same ultrasound probe.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Non-limiting examples of various embodiments of the present disclosure will next be described in relation to the drawings, in which:

[0010] FIG. **1** shows a curvilinear ultrasound probe with example physical transducer adapters, in accordance with at least one embodiment of the present invention;

[0011] FIG. **2** shows the ultrasound probe of FIG. **1** being provided with a cardiac adapter, in accordance with at least one embodiment of the present invention;

[0012] FIG. **3** shows the time delays and apertures used to perform beamforming during operation of an ultrasound probe with a cardiac adapter attached, in accordance with at least one embodiment of the present invention;

[0013] FIG. **4** shows a cross-sectional view of the ultrasound probe's transducer array and the cardiac adapter shown in FIG. **2**, in accordance with at least one embodiment of the present invention;

[0014] FIG. **5** shows the ultrasound probe of FIG. **1** being provided with a linear adapter, in accordance with at least one embodiment of the present invention;

[0015] FIG. **6** shows the time delays and apertures used to perform beamforming during operation of the ultrasound probe with the linear adapter attached, in accordance with at least one embodiment of the present invention;

[0016] FIG. **7** shows a cross-sectional view of the ultrasound probe's transducer array and the linear adapter shown in FIG. **5**, in accordance with at least one embodiment of the present invention;

[0017] FIG. **8** shows a bottom view of the ultrasound probe and linear adapter of FIG. **5**, in accordance with at least one embodiment of the present invention;

[0018] FIG. **9** shows a curvilinear ultrasound probe with example physical transducer adapters, in accordance with at least one embodiment of the present invention;

[0019] FIG. **10** shows an interior perspective views of the cardiac adapter and linear adapter of FIG. **9**, in accordance with at least one embodiment of the present invention;

[0020] FIG. **11** shows a close-up perspective view of a pass-through volume component for the linear adapter in relation to an ultrasound probe, in accordance with at least one embodiment of the present invention;

[0021] FIG. **12** is a flowchart diagram showing steps of a method for generating ultrasound images with an ultrasound imaging transducer and transducer adapter, in accordance with at least one embodiment of the present invention;

[0022] FIG. **13** shows an interior perspective views of an alternative embodiment of the cardiac adapter and linear adapter, in accordance with at least one embodiment of the present invention;

[0023] FIG. **14** shows a cross-sectional view of the cardiac adapter and linear adapter of FIG. **13**, in accordance with at least one embodiment of the present invention; and

[0024] FIG. **15** shows the different imaging configurations of the ultrasound imaging probe and example cardiac and linear transducer adapters, in accordance with at least one embodiment of the present invention.

DETAILED DESCRIPTION

[0025] In a first broad aspect of the present disclosure, there is provided an ultrasound imaging assembly, including an ultrasound imaging transducer having transducer elements configured in a curved geometry; and a transducer adapter for coupling to the ultrasound imaging transducer, wherein the transducer adapter includes a pass-through volume for permitting ultrasound energy to be transmitted through the transducer adapter, the pass-through volume including: a proximal surface for mating to the transducer, the proximal surface having a curvature corresponding to the curved geometry of the transducer elements; and a distal surface at a distal end of the transducer assembly, the distal surface having a geometry that is substantially planar.

[0026] In some embodiments, the transducer adapter is configured to releasably couple to the ultrasound imaging transducer.

[0027] In some embodiments, the ultrasound imaging transducer assembly is configured to determine an adapter type of the transducer adapter. In some embodiments, the ultrasound imaging transducer assembly includes a sensor for determining the adapter type of the transducer adapter.

[0028] In some embodiments, the transducer adapter includes a radio frequency identification (RFID) tag and the sensor includes a radio frequency identification (RFID) sensor.

[0029] In some embodiments, the transducer adapter includes an image signature feature readable by the ultrasound imaging transducer to determine when the transducer adapter is coupled to the ultrasound imaging transducer.

[0030] In some embodiments, the pass-through volume includes at least one of agar, agarose, Aqualene™, silicone, polyvinyl alcohol, polyvinyl alcohol gel, polyacrylamide gel, open porosity foam, gelatin gel, oil gel, polyurethane gel, epoxy plastisol, silicon rubber, swollen segmented polyurethane gel (S-SPUG), urethane polymer, tofu, magnesium silicate, and Zerdine™.

[0031] In some embodiments, the ultrasound transducer elements have a first elevational length and the proximal surface has a second elevational length, different from the first elevational length.

[0032] In another broad aspect of the present disclosure, there is provided a method of generating ultrasound images with an ultrasound imaging transducer, the ultrasound imaging transducer having a native footprint, the method including: coupling a transducer adapter to the ultrasound imaging transducer, wherein the transducer adapter has a proximal end configured to mate to the ultrasound imaging transducer and a distal end that defines a contact surface, wherein the contact surface corresponds to an adapted footprint different from the native footprint; modifying at least one imaging parameter so that, during imaging, ultrasound signals emitted from the ultrasound imaging transducer travels through the transducer adapter and exits the contact surface, and the exiting ultrasound signals have one or more characteristics substantially similar to other ultrasound signals emitted from another ultrasound imaging transducer having the adapted footprint as its native footprint; and generating the ultrasound images with the modified at least one imaging parameter.

[0033] In some embodiments, after the transducer adapter is coupled, the modified at least one imaging parameter causes at least one of the ultrasound signals emitted from the ultrasound imaging transducer to be steered in a direction away from normal to the native footprint of the ultrasound imaging transducer.

[0034] In some embodiments, the ultrasound imaging transducer emits non-steered ultrasound signals during imaging prior to the transducer adapter being coupled.

[0035] In some embodiments, the modified at least one imaging parameter includes at least one of time delay and aperture, to cause at least one of the ultrasound signals to be steered in the direction away from normal to the native footprint of the ultrasound imaging transducer.

[0036] In some embodiments, the modified at least one ultrasound imaging parameter includes at least one of time delay, sequence, steering angle, transmit aperture size, transmit aperture location, receive aperture size, receive aperture location, and image zero point.

[0037] In some embodiments, the adapted footprint includes a cardiac footprint, and the exiting ultrasound signals are steered in respective different directions so that a substantial portion of a sector image is generated.

[0038] In some embodiments, the adapted footprint includes a linear footprint, and the steered at least one of the ultrasound signals emitted from the ultrasound imaging transducer results in the exiting ultrasound signals being projected orthogonally to the contact surface.

[0039] In some embodiments, the exiting ultrasound signals are parallel so that a rectangular image is generated.

[0040] In some embodiments, after coupling the transducer adapter, the method includes determining an adapter type of the transducer adapter, wherein the adapter type is based on at least one of a geometry of: the proximal end configured to mate to the ultrasound imaging transducer, and a geometry of the contact surface.

[0041] In some embodiments, the modifying of the at least one imaging parameter is based at least in part on the adapter type.

[0042] In some embodiments, the ultrasound imaging transducer includes a sensor and determining the adapter type of the transducer adapter includes sensing the adapter type of the transducer adapter using the sensor.

[0043] In some embodiments, an image signature feature is provided on the transducer adapter that is readable when the transducer adapter is coupled to ultrasound imaging transducer, and determining the adapter type of the transducer adapter includes: generating an ultrasound image, and identifying the image signature feature on the ultrasound image to determine the adapter type of the transducer adapter.

[0044] In some embodiments, determining the adapter type of the transducer adapter includes: receiving input at the ultrasound imaging transducer, the input indicating the adapter type of the transducer adapter. For example, the input may be provided via a suitable user interface on a computing device that controls and/or communicates with the ultrasound imaging transducer.

[0045] In some embodiments, the adapter type includes at least one of a cardiac phased array contact surface and a linear array contact surface.

[0046] In another broad aspect of the present disclosure, there is provided a transducer adapter for coupling to an ultrasound imaging transducer with a native footprint, the transducer adapter including: a proximal end configured to mate to the ultrasound imaging transducer; and a distal end that defines a contact surface, wherein the contact surface corresponds to an adapted footprint different from the native footprint; wherein when the transducer is coupled to the ultrasound imaging transducer, ultrasound signals emitted from the ultrasound imaging transducer travels through the transducer adapter and exits the contact surface, and the exiting ultrasound signals have one or more characteristics that are substantially similar to ultrasound signals emitted from another ultrasound imaging transducer having the adapted footprint as its native footprint.

[0047] In some embodiments, the transducer adapter includes a pass-through volume for permitting the ultrasound signals to be transmitted through the transducer adapter.

[0048] In some embodiments, the pass-through volume includes at least one of agar, agarose, Aqualene™, silicone, polyvinyl alcohol, polyvinyl alcohol gel, polyacrylamide gel, open porosity foam, gelatin gel, oil gel, polyurethane gel, epoxy plastisol, silicon rubber, swollen segmented polyurethane gel (S-SPUG), urethane polymer, tofu, magnesium silicate, and Zerdine™.

[0049] In some embodiments, the transducer adapter includes an image signature feature readable by the ultrasound imaging transducer when the transducer adapter is couple to the ultrasound imaging transducer.

[0050] For simplicity and clarity of illustration, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements or steps. In addition, numerous specific details are set forth in order to provide a thorough understanding of the exemplary embodiments described herein. However, it will be understood by those of ordinary skill in the art that the embodiments described herein may be practiced without these specific details. In other instances, certain steps, signals, protocols, software, hardware, networking infrastructure, circuits, structures, techniques, well-known methods, procedures and components have not been described or shown in detail in order not to obscure the embodiments generally described herein.

[0051] Furthermore, this description is not to be considered as limiting the scope of the embodiments described herein in any way. It should be understood that the detailed description, while indicating specific embodiments, are given by way of illustration only, since various changes and modifications within the scope of the disclosure will become apparent to those skilled in the art from this detailed description. Accordingly, the specification and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

[0052] Referring to FIG. **1**, shown there generally as **100** is a curvilinear ultrasound probe with example physical transducer adapters, in accordance with at least one embodiment of the present invention. As illustrated, the curvilinear probe **100** is provided in the form of a handheld wireless scanner that may be configured to communicate with an external wireless computing device containing a display (not shown). However, in other embodiments, the ultrasound probe can be provided in other forms. For example, the physical adapters may be used with an ultrasound probe that can be attached via a cord to a separate ultrasound machine. While generally referred herein as ultrasound probe **100**, the ultrasound probe **100** may in some instances additionally or alternatively be referred to as an ultrasound imaging transducer herein.

[0053] Different hardware adapters **150**, **170** may be attached to the probe head **102**. The hardware adapters **150**, **170** may each have a surface **120** that is constructed so that it conforms to the to the exterior surface of the probe head **102**. In the illustrated embodiments, the hardware adapters **150**, **170** each have a cavity with such mating surface **120** provided on the interior of the cavity. The housing of the adapters **150**, **170** may be made of any suitable material. For example, in some embodiments, the housing of the adapters **150**, **170** may be made of molded plastic. When the different adapters **150**, **170** are each attached the probe head **102**, the ultrasound signals emitted from the probe head **102** may be directed in a manner that allows for their transmission through a pass-through volume (discussed below) of the adapters **150**, **170**, so that the signals exit from the non-attached surfaces **154**, **174** of the adapters **150**, **170** respectively. Echoes corresponding to the transmitted ultrasound signals can be received via the same pass-through volumes at the probe head **102**.

[0054] To allow the ultrasound signals to travel through the adapters **150**, **170**, the adapters **150**, **170** may be constructed so that the pass-through volumes through which the ultrasound signals travel are provided with an acoustically transparent material. For example, the acoustically transparent material may be a phantom-like material or an epoxy (e.g., an epoxy material that may be similar to what is be provided on the surface of the probe head **102** itself. In various embodiments, the acoustically transparent material may additionally or alternatively be made of one or more of agar, agarose, Aqualene™, silicone, polyvinyl alcohol, polyvinyl alcohol gel, polyacrylamide gel, open porosity foam, gelatin gel, oil gel, polyurethane gel, epoxy plastisol, silicon rubber, swollen segmented polyurethane gel (S-SPUG), urethane polymer, tofu, magnesium silicate, and/or Zerdine™. In an example embodiment, Aqualene™ M320 from Olympus Corporation may used as the material for the pass-through volume. The acoustically transparent material of the pass-through volumes may extend from the attached surfaces **120** to the respective non-attached surfaces **154**, **174** of the adapters **150**, **170**.

[0055] The non-attached surfaces **154**, **174** may be placed against the skin of a patient to perform examinations. By providing acoustically transparent material at the interface of the probe head **102** and the attached surfaces **120** of the adapters **150**, **170**, and also through the interior pass-through volumes of the adapters **150**, **170**, there may be minimal loss of acoustic energy due to reflection or refraction prior to the ultrasound energy entering patient tissue. In some embodiments, a coupling agent (e.g., ultrasound gel) may be placed on the attached surfaces **120** of the adapters **150**, **170** prior to attaching the adapters to the probe head **102**. In various embodiments, the non-attached surfaces **154**, **174** of the adapters **150**, **170** may also be provided with an acoustically transparent material so that the ultrasound signals can be emitted therefrom and received thereat with minimal loss of acoustic energy. While the term pass-through volume is generally used herein, the same element may generally be referred to as the "lens" of a transducer adapter **150**, **170** in various instances herein.

[0056] The element described herein generally as attached surface **120** may in certain instances also be referred to as the proximal surface of the transducer adapters **150**, **170**. Likewise, the element described herein as non-attached surfaces **154**, **174** may also be referred to as the distal surface. Further, since the attached surface **120** may mate with the transducer adapters **150**, **170** when a transducer adapter **150**, **170** is attached, the attached surface **120** may additionally or alternatively be considered a mating surface. Likewise, since the non-attached surfaces **154**, **174** may contact an object (e.g., skin) during imaging when the adapters **150**, **170** are attached, the non-attached surfaces **154**, **174** may additionally or alternatively be considered a contact surface. As discussed herein, the mating surface **120** is generally described as forming an acoustic coupling with an exterior surface of the transducer where ultrasound signals are emitted/received. This coupling may be formed via direct or indirect physical contact. For example, in various embodiments, the mating surface **120** and the transducer may not form physical contact. Instead, the acoustic coupling may be formed indirectly through a suitable acoustic coupling agent such as ultrasound gel.

[0057] In various embodiments, the nosepiece **104** holding the transducer array on the ultrasound probe **100** may be configured with a mechanism to allow for attachment of the adapters **150**, **170**. For example, the nosepiece **104** may be provided with a number of slots or grooves **106** for receiving corresponding clamps or clips **152**, **172** on the adapters **150**, **170**. The clips **152**, **172** may slide over the body of the nosepiece **104** to engage the grooves **106**. The adapters **150**, **170** may be removed, for example, by physically pulling on the adapters **150**, **170** so that clips **152**, **172** disengage. Other methods of attaching the adapters **150**, **170** to the nosepiece **104** may be possible. For example, a slidable latch may be provided in some embodiments. Additionally or alternatively, the adapters **150**, **170** may be secured on the nosepiece **104** via a friction fit (e.g., without grooves **106** or clamps **152**, **172**).

[0058] Two example transducer adapters are shown in FIG. **1**: a cardiac adapter **150** and linear adapter **170**. The operation of the cardiac adapter **150** is discussed below with respect to FIGS. **2-4**. The operation of the linear adapter **170** is discussed below with respect to FIGS. **5-8**. In the illustrated example embodiment, the transducer array provided on the probe head **102** is a curvilinear transducer array. However, in other embodiments, the principles discussed herein may be applied to configure ultrasound probes with other transducer array configurations to operate with hardware adapters to provide different ultrasound probe footprints and imaging capabilities.

[0059] The cardiac adapter **150** and linear adapter **170** may be considered two examples of transducer adapter types. Other adapter types may be defined based on the geometry of the attached surface **120** and non-attached surfaces of given the transducer adapters. As noted, these the attached surface **120** and non-attached surfaces discussed herein may also be referred to as the mating surface and contact surface, respectively.

[0060] Referring to FIG. **2**, shown there generally as **200** is the ultrasound probe of FIG. **1** being provided with a cardiac adapter **150**, in accordance with at least one embodiment of the present invention. As illustrated, the adapter **150** is attached to the nose piece **104** of the curvilinear probe **100** of FIG. **1**, and the probe head **102** (shown in dotted outline) is mated to the attached surface **120** of the cardiac adapter **150**. The non-attached surface **154** of the adapter **150** is shaped like a traditional phased-array cardiac probe. Specifically, the non-attached surface **154** is provided with a smaller footprint that allows for better insertion of the non-attached surface **154** in the intercostal space. The smaller footprint may allow the lowering of the non-attached surface **154** into the intercostal space so that the zero point of the image is slightly lower (e.g., by 5 millimeters). This may allow for improved imaging of the heart. For ease of reference, the cardiac adapter **150** is referred to herein as the "cardiac" adapter. However, it will be understood by persons skilled in the art that the ultrasound probe **100** when operating with such adapter **150** attached may provide phased-array imaging that is usable in non-cardiac medical examinations.

[0061] Traditional phased-array cardiac probes have a small footprint and thus a small transducer array provided on its probe head. To provide a sufficiently large field of view, these probes may repeatedly activate the transducer elements and steer ultrasound signals in a variety of directions. This results in a sector image. When the cardiac adapter **150** is attached to the ultrasound probe **100** in the present embodiments, a similar set of sweeping ultrasound signals may be transmitted from the relatively smaller footprint of the non-attached surface **154** of the cardiac adapter **150**. To accomplish this, the ultrasound sequence in which the elements of the transducer array is activated may be altered. For example, different subsets of the transducer elements may be selectively activated and steered so as to project the ultrasound signals **210** in the manner shown in FIG. **2** to obtain a sector image with its apex at the non-attached surface **154** of the cardiac adapter **150**. Additional teachings related to how subsets of the transducer elements within a transducer array may be activated and selectively steered are discussed in Applicant's U.S. patent application Ser. No. 15/207,203 (referred to herein as "Applicant's Virtual Phased-array Application"), which is hereby incorporated by reference in its entirety.

[0062] Referring to FIG. **3**, shown there generally as **300** are the time delays and apertures used to perform beamforming when the transducer array of the curvilinear probe **100** is activated with the cardiac adapter **150** attached thereto, in accordance with at least one embodiment of the present invention. FIG. **3** shows a simplified view of a transducer head **102** with its constituent transducer elements **350** and how they are pulsed at three example points in time during generation of an ultrasound image when the cardiac adapter **150** is attached.

[0063] Beamforming involves applying a time delay to when adjacent transducer elements **350** are pulsed so that the interference pattern generated by ultrasound signals **210** form a beam when projected. By varying the time delay and sequence in which the transducer elements **350** within a selected subset of the transducer elements are pulsed, the beam can be steered.

[0064] To generate a sector image from the non-attached surface **154** of the cardiac adapter **150**, ultrasound beams are transmitted from selected groups of adjacent transducer elements **350** across a middle portion of the transducer array. These ultrasound beams result in the formation of scanlines that collectively generate the ultrasound image. The position of the transducer elements **350** on the probe head **102** where the ultrasound signals **210** get generated may be called the "aperture". As will be understood by persons skilled in the art, ultrasound operation may involve a transmit aperture and a receive aperture. The transmit aperture refers to the transducer elements **350** that are activated when the ultrasound signals **210** are generated, and the receive aperture refers to the transducer elements **350** that receive echo energy in response. The two apertures may be different such that they include different groups of transducer elements **350**. Unless specifically indicated, the term "aperture" refers to the transmit aperture herein.

[0065] At the first point in time, the aperture **304**A is on a portion of the transducer array that is right of the center point of the transducer array, so that a group of adjacent transducer elements **350** there are pulsed. This group of adjacent transducer elements **350** are pulsed according to a time delay **302**A. The time delay **302**A is illustrated as an arc that represents the sequence of activation when the transducers elements **304**A are pulsed. As shown, the time delay **302**A shown has the rightmost transducer elements **350** within the aperture **304**A being activated first and then progressively shifting to the left of the aperture **304**A in the sequence and manner represented by the time delay **302**A. The time delay **302**A will cause the ultrasound signal **210**A to be directed to the left. Such an ultrasound signal **210**A may be projected through the pass-through volume **310** (as may be filled with epoxy or other acoustically transparent material) of the cardiac adapter **150** so as to exit the cardiac adapter **150** through the apex of the resultant sector image (shown as a dot in FIG. **3**) at the non-attached surface **154** in the direction shown (e.g., as ultrasound signal **210**A').

[0066] At the second point in time, the aperture **304**B is in the center portion of the transducer array. The time delay **302**B that is applied starts with the outermost transducer elements **350** of the aperture **304**B being pulsed first, and then transducer elements **350** towards the center of the aperture **304**B are progressively pulsed. This type of time delay **302**B may generate an ultrasound beam **210**B that focuses in a direction orthogonal to the surface of the probe head **102**. The ultrasound beam **210**B may travel through the pass-through volume **310** and exit the cardiac adapter **150** through the apex of the resultant sector image at the non-attached surface **154** (e.g., as ultrasound signal **210**B').

[0067] At the third point in time, the aperture **304**C is on a portion of the transducer array that is left of the center point of the transducer array, so that a group of adjacent transducer elements **350** there are pulsed. This group of adjacent transducer elements **350** are pulsed according to a time delay **302**C. As shown, the time delay **302**C shown has the leftmost transducer elements **350** within the aperture **304**C being activated first and then progressively shifting to the right of the aperture **304**C in the sequence and manner represented by the time delay **302**C. The time delay **302**C will cause the ultrasound signal **210**C to be directed to the right. Such an ultrasound signal **210**C may be projected through the pass-through volume **310** of the cardiac adapter **150** so as to exit the cardiac adapter **150** through the apex of the resultant sector image at the non-attached surface **154** in the direction shown (e.g., as ultrasound signal **210**C').

[0068] By selectively identifying apertures **304**A, **304**B, **304**C and activating them with respective time delays **302**A, **302**B, **302**C, the distance between the probe head **102** and the non-attached surface **154** of the cardiac adapter **150** may be accounted for. This may allow the ultrasound signals emitted from the smaller footprint of the cardiac adapter **150**'s non-attached surface **154** to have characteristics that are substantially similar to ultrasound signals that are emitted from a separate dedicated small footprint phased-array transducer. For example, the ultrasound signals **210** exiting the contact surface of the cardiac adapter **150** can mimic the ultrasound signals emitted from a traditional phased-array transducer, and provide analogous ultrasound imaging without the need of a separate dedicated small footprint phased-array probe.

[0069] Referring to FIG. **4**, shown there is a cross-sectional view of the transducer array of the ultrasound probe and cardiac adapter of FIG. **2**, in accordance with at least one embodiment of the present invention. FIG. **4** shows a simplified view of a transducer element **350** in the transducer array, with its bottom surface corresponding to the probe head **102**. For ease of illustration, the transducer element **350** is shown as being positioned adjacent the pass-through volume **310** (shown in hatched shading) of the cardiac adapter **150**, without showing intermediate layers such as the matching layers or the acoustic lens. As illustrated, the transducer element **350** has an elevation length **405**, and the corresponding portion of the attached surface **120** of the cardiac adapter **150** that mates with the transducer element **350** has a matching elevation length, so that the elevation/slice thickness resolution of the transducer element **350** can be maintained when ultrasound signals are emitted from the non-attached surface **154**.

[0070] Referring to FIG. **5**, shown there generally as **500** is the ultrasound probe of FIG. **1** being provided with a linear adapter, in accordance with at least one embodiment of the present invention. As illustrated, the linear adapter **170** is attached to the curvilinear probe **100** of FIG. **1**, and the probe head **102** is mated to the attached surface **120** of the linear adapter **170**. The linear adapter **170** is configured so that the footprint of its non-attached surface **174** is shaped like a traditional linear-array probe. When operating with the linear adapter **170** attached, the frequency of the ultrasound signals emitted may be lower than what is typically transmitted from a traditional linear ultrasound probe. However, the lower frequency may still be suitable for certain types of examinations (e.g., vascular). At the same time, in contrast to the curved configuration of the curvilinear transducer array, the flat footprint of the linear adapter **170** may allow for improved contact with the skin to perform such examinations.

[0071] Traditional linear-array probes may sequentially project parallel ultrasound signals across the transducer array, so as to produce a rectangular image. When the linear adapter **170** is attached to the ultrasound probe **100** in the present embodiments, a similar set of parallel ultrasound signals may be transmitted from the non-attached surface **174** of the linear adapter **170**. To project a similar set of ultrasound signals from the linear footprint of the linear adapter **170**, the time delays and sequence in which the elements of the transducer array are activated may be altered. For example, as illustrated, different subsets of the transducer elements may need to be activated so as to project the ultrasound signals **210** in the manner shown to obtain a rectangular image.

[0072] Referring to FIG. **6**, shown there generally as **600** are the time delays and apertures used to perform beamforming when the transducer array of the curvilinear probe **100** is activated with the linear adapter **170** attached thereto, in accordance with at least one embodiment of the present invention. By varying the time delay and sequence in which the transducer elements **350** within a subset of the transducer elements are pulsed, the beams can be steered so as to provide ultrasound beams that are emitted from the non-attached surface **174** that mimic those typically emitted from a linear-array probe.

[0073] FIG. **6** shows a simplified view of the transducer array provided on probe head **102** with its constituent transducer elements **350** and how they are pulsed at three example points in time during generation of an ultrasound image when the linear adapter **170** is attached. To generate a rectangular image, ultrasound beams are transmitted from selected groups of adjacent transducer elements **350** sequentially and successively across a portion of the transducer array that excludes the peripheral transducer elements.

These ultrasound beams result in the formation of parallel scanlines that collectively generate the rectangular ultrasound image.

[0074] At the first point in time, the aperture **604**A is on a portion of the transducer array **102** that is proximately above the left edge of the non-attached surface **174** of the linear adapter **170**, so that a group of adjacent transducer elements **350** there are pulsed. This group of adjacent transducer elements **350** are pulsed according to a time delay **602**A. The time delay **602**A is illustrated as an arc that represents the sequence of activation when the transducers elements **604**A are pulsed. As shown, the time delay **602**A shown has the leftmost transducer elements **350** within the aperture **604**A being activated first and then progressively shifting to the right of the aperture **604**A in the sequence and manner represented by the time delay **602**A. The time delay **602**A will cause the ultrasound signal **210**D to be steered in a manner that is angled away from the azimuth/normal at aperture **604**A. However, the signal **210**D will be projected through the pass-through volume **610** (e.g., containing epoxy or other acoustically transparent material) of the linear adapter **170** so as to exit the linear adapter **170** in a direction that is orthogonal to the non-attached surface **174** (e.g., as ultrasound signal **210**D').

[0075] At the second point in time, the aperture **604**B is in the center portion of the transducer array. Similar to the time delay **302**B shown in FIG. **3**, the time delay **602**B that is applied starts with the outermost transducer elements **350** of the aperture **604**B being pulsed first, and then transducer elements **350** towards the center of the aperture **604**B are progressively pulsed. This type of time delay **602**B may generate an ultrasound beam **210**E that focuses in a direction orthogonal to the surface of the probe head **102**. The ultrasound beam **210**E may travel through the pass-through volume **610** and exit the linear adapter **170** in a manner that is also orthogonal to the non-attached surface **174** (e.g., as ultrasound signal **210**E').

[0076] At the third point in time, the aperture **604**C is on a portion of the transducer head **102** that is proximately above the right edge of the non-attached surface **174** of the linear adapter **170**. This group of adjacent transducer elements **350** are pulsed according to a time delay **602**C. As shown, the time delay **602**C has the rightmost transducer elements **350** within the aperture **604**C being activated first and then progressively shifting to the left of the aperture **604**C in the sequence and manner represented by the time delay **602**C. The time delay **602**C will cause the ultrasound signal **210**F to be angled away from the azimuth at aperture **604**C. However, the signal **210**F will be projected through the pass-through volume **610** of the linear adapter **170** so as to exit the linear adapter **170** in a direction that is orthogonal to the non-attached surface **174** (e.g., as ultrasound signal **210**F').

[0077] Referring to FIG. **7**, shown there generally as **700** is a cross-sectional view of the ultrasound probe **100**'s transducer array and the linear adapter shown in FIG. **5**, in accordance with at least one embodiment of the present invention. FIG. **7** shows a simplified view similar to FIG. **4** discussed above. In addition to parallel ultrasound beams in the lateral direction, traditional linear ultrasound probes also typically have transducer elements with a shorter elevation length so as to provide finer elevation (also called slice thickness) resolution.

[0078] As in FIG. **4**, the transducer element **350** shown in FIG. **7** has an elevation length **405**. However, with the linear adapter **170** attached, the pass-through volume **610** of the adapter **170** has an elevation length **705** that is shorter than the elevation length **405** of the transducer elements on the probe head **102**. This may allow for the ultrasound signals being emitted from the linear adapter **170** to be masked in the elevation direction, so as to provide an imaging slice thickness that is similar to that which is provided with traditional linear ultrasound probes.

[0079] Referring to FIG. **8**, shown there generally as **800** is a bottom view of the ultrasound probe and linear adapter of FIG. **5**, illustrating the masking of ultrasound signals achieved by the linear adapter, in accordance with at least one embodiment of the present invention. In FIG. **8**, the width **810** and elevation length **405** of the transducer array for the curvilinear probe head **102** is shown. As illustrated, it can be seen that masking of the ultrasound signals typically transmitted from the transducer array of the curvilinear probe **100** is performed in multiple dimensions. For example, in the horizontal direction, it can be seen that the masking by the pass-through volume **610** may narrow the width of ultrasound signals that would typically be transmitted by the transducer array to the narrower width **805** of the non-attached surface **174** of the linear adapter **170**. When this narrower width **805** is used with the modified ultrasound sequence discussed above with respect to FIG. **6**, parallel ultrasound signals may be emitted from the non-attached surface **174** of the linear adapter **170** in a manner similar to that typically emitted from a traditional linear array probe. In the elevation length direction, it can be seen that the pass-through volume **610** also narrows the elevation length from the elevation length **405** of the transducer elements **350** to the narrower elevation length **705**.

[0080] Various mechanisms may be used to accomplish the masking of ultrasound signals discussed herein. For example, the volume corresponding to the masked area (shown without hatched shading in FIG. **8**) may be provided with material that absorbs and/or disperses ultrasound energy. Referring simultaneously to FIG. **7**, in some embodiments, such material may be provided in any portion of the volume adjacent the pass-through volume **610**. For example, such material may be provided as an air gap since air has low acoustic impedance and is highly absorbing. In various embodiments, other low acoustic impedance material can be used.

[0081] Additionally or alternatively, the linear adapter **170** may be provided with reflectors **720** adjacent the pass-through volume **610**. By angling the reflectors **720** in a manner that reflect ultrasound energy away from the probe head **102**, the ultrasound energy transmitted from the transducer element **350** that should be masked may be dispersed and only the desired ultrasound energy will travel through the pass-through volume **610** into the tissue and corresponding echoes will be received by the transducer element **350**. In various embodiments, image analysis can be performed to identify the absorbed and/or dispersed signals caused by the air and/or reflectors **720** so as to discard such image data.

[0082] In various embodiments, when acquiring ultrasound images using the adapters **150**, **170**, the zero point of the ultrasound image (also called the apex in the case of sector imaging) may be set to be the depth of the non-attached surface **154**, **174** of the respective adapters **150**, **170** (instead of at the probe head **102**). This may allow any image data collected from imaging depths shallower than the non-attached surface **154**, **174** to be discarded. For example, referring again to FIG. **7**, even in embodiments where the volume adjacent the pass-through volume **610** is provided with materials or mechanisms that will absorb and/or disperse the ultrasound energy to be masked (e.g., as may be dispersed by reflectors **720**), there may nevertheless still be ultrasound energy that is not dispersed/absorbed but is reflected. By configuring the zero point of the ultrasound image to be the depth of the non-attached surface **154**, **174**, any reflected ultrasound energy emanating from such material and/or mechanism is unlikely to get incorrectly characterized as legitimate image data. Moreover, such configuration may help ensure that the reflected ultrasound energy (if any) resulting from the pass-through volumes **310**, **610** of the adapters **150**, **170**, and/or the interface between the probe head **102** and the attached surfaces **120** of the adapters **150**, **170**, and/or the interface between the non-attached surface **154**, **174** of the adapters **150**, **170** and the skin all also do not get incorrectly characterized as legitimate image data.

[0083] The various embodiments discussed herein may facilitate imaging multiple patient areas using a single ultrasound transducer. For example, when used in a conventional context, a curvilinear probe **100** may be used to image the abdomen. However, with the attachment of the adapters **150**, **170** discussed herein, the same curvilinear probe **100** may also be used to perform imaging that would typically require two additional probes (e.g., a traditional phased-array cardiac probe and a traditional linear probe). Put another way, the present embodiments may allow the single curvilinear probe **100** to serve the needs that would typically be served by three different ultrasound probes.

[0084] Various mechanisms may be used to configure the curvilinear probe **100** to employ the appropriate ultrasound sequence for the adapter **150**, **170** that is attached. For example, in some embodiments, there may be a software setting that can be selected to configure the curvilinear probe **100** to modify its ultrasound sequence to activate in the manner discussed above with respect to FIG. **3** (e.g., if a cardiac adapter **150** is attached) or in the manner discussed above with respect to FIG. **6** (e.g., if a linear adapter **170** is attached).

[0085] Additionally or alternatively, electronic pins, connectors, or other like mechanism may be provided on the adapters **150**, **170** so that they can couple with corresponding electronic components provided on the nosepiece **104**. For example, when an electric connection is formed between such electronic components, the type of adapter **150**, **170** can be communicated to the curvilinear probe **100** and the curvilinear probe **100** may alter its ultrasound sequence accordingly.

[0086] In some embodiments, the curvilinear probe **100** may be configured to automatically detect when an adapter **150**, **170** is attached. For example, the curvilinear probe **100** and/or software controlling its operation may be configured to recognize pre-set image patterns generated from the reflections of the attached surfaces **120** of the adapters **150**, **170** (as shown in FIG. **1**). As the attached surfaces **120** of the adapters **150**, **170** may produce distinct image patterns when ultrasound energy transmitted according to a conventional curvilinear ultrasound sequence is emitted from the probe head **102**, such image patterns may be stored in memory so that upon initialization of the curvilinear probe **100**, a test scan is performed. If the image data collected from the test scan matches any of the stored image patterns, then it may be determined that the adapter **150**, **170** corresponding the stored image pattern is attached to the curvilinear probe **100** and the ultrasound sequence may be modified accordingly.

[0087] In some embodiments, to assist with generation and identification of such pre-set image patterns, the makeup of the non pass-through volume of an adapter **150**, **170** (e.g., for the linear adapter **170**, the volume corresponding to the non-hatched area shown in FIG. **8**) may be constructed so as to provide a specific image signature that can be identified by the ultrasound device **100**. For example, such volume may be created from a mixture of air and low acoustic impedance material such as acrylonitrile butadiene styrene (ABS), with the mixture being formed in a way that provides an image signature when ultrasound signals are projected onto it and reflected therefrom.

[0088] In another example, structures may be placed on the attached surfaces **120** (as shown in FIG. **1**) beside the exposed surface of pass-through volumes **310**, **610** discussed above. These structures can indirectly mate to the transducer array provided on the probe head **102** when the adapters **150**, **170** are attached, so as to provide distinct image signatures that assist in identifying when a transducer adapter is attached and/or the type of transducer adapter attached. In various embodiments, the structures may be a metal plate or post, and the image signature may include the appearance of the structures when the structures are being imaged (e.g., using a traditional curvilinear ultrasound sequence). In various embodiments, the image signatures may include specific image artifacts that is created when imaging the structures (e.g., a comet tail or ring-down artifact).

[0089] Referring to FIG. **9**, shown there generally as **900** is a curvilinear ultrasound probe with example physical transducer adapters, in accordance with at least one embodiment of the present invention. Different transducer adapters **150'**, **170'** may be attached to the probe head **102'**. A nosepiece **104'** for holding the transducer array on the ultrasound probe **100** may be provided and configured with a mechanism to allow attachment of the adapters **150'**, **170'**. In the illustrated embodiment, nosepiece **104'** may be provided with divots **106'**. Transducer adapters **150'**, **170'** may be provided with corresponding protrusions **152'**, **172'** so that a snap fit can be formed between transducer adapters **150'**, **170'** and nosepiece **104'**. In the example shown, hemispherical-shaped divots **106'** and corresponding protrusions **152'**, **172'** are provided; however, any suitable shape may be used. Also, as illustrated, the divots **106'** are provided on the nosepiece **104'** and the corresponding protrusions **152'**, **172'** are provided on the adapters **150'**, **170'**; however, in various embodiments, the divots may be provided on the adapters **150'**, **170'**, and the protrusions provided on the nosepiece **104'**. In various embodiments, there may be different numbers of attachment mechanisms (e.g., divots and corresponding protrusions) other than what is shown.

[0090] As shown in FIG. **9**, transducer adapters **150'**, **170'** may be provided with one or more locator posts **958**, **978** designed to be positioned against one or more locator slots **908** on nosepiece **106'**. Locator posts **958**, **978** may be configured to maintain a predetermined desired positioning of transducer adapters **150'**, **170'** with respect to noise piece **104'**. When the cardiac adapters **150'**, **170'** attached, the locator posts **958**, **978**, abut against the slots **908**. In addition to maintaining positioning, the interaction between the posts **958**, **978** and the slots **908** may prevent the adapters from being pushed too far over the nosepiece **104'**. In this manner, the posts **958**, **978** and slots **908** may prevent damage of the transducer array of the ultrasound probe **100**.

[0091] Similar to the example adapters **150**, **170** with corresponding non-attached surfaces **154**, **174** (also referred to as contact surfaces) shown in FIG. **1**, non-attached surfaces **154'**, **174'** form the distal end of respective pass-through volumes in the example adapters **150'**, **170'** of FIG. **9**. These contact surfaces **154'**, **174'** may contact the object (e.g., anatomy) being imaged.

[0092] Referring to FIG. **10**, shown there generally as **1000** is an interior perspective view of the cardiac adapter and linear adapter of FIG. **9**, in accordance with at least one embodiment of the present invention. This view shows protrusions **152'**, **172'** and posts **958**, **978** used to attach the transducer adapters to ultrasound probe **100**. This view also more clearly illustrates the components forming the pass-through volumes **310**, **610** of the adapters **150'**, **170'**. As illustrated, each of the pass-through volumes **310**, **610** has a respective proximal surface **120** that is configured to mate with the probe head **102** of ultrasound probe **100**.

[0093] Generally, it is desirable for the distance between the contact surface **154'**, **174'** and the proximal surface **120** of the adapters **150'**, **170'** (e.g., the height of the pass-through volumes **310**, **610**) to be as short as a possible. By having the pass-through volumes **310**, **610** have a short height, reverberation artifacts that result when ultrasound energy hits the attached (mating) surface **120** and the contact surface **154'**, **174'** may be minimized. Also, since ultrasound energy emitted at predetermined frequencies may have a limited penetration depth, having the height of the pass-through volume **310**, **610** be as short as possible may maximize the depth that the ultrasound signals can penetrate into the body and effectively image when the adapters **150'**, **170'** are attached.

[0094] At the same time, there may be constraints as to how short the pass-through volumes **310**, **610** can be. For example, in some embodiments, the pass-through volume **310**, **610** may be separately manufactured (e.g., molded) out of a suitable acoustically-transparent material and, during manufacturing, adhered to the housing of an adapter **150'**, **170'**. Configuring the pass-through volume **310**, **610** to be too short may make manufacturing difficult (e.g., because the molded material may not be sufficiently rigid to facilitate ease of adhesion to an interior surface of the housing of the adapters **150'**, **170'**). Also, as discussed below with respect to FIG. **11**, for the linear adapter **170'**, the height of the pass-through volume needs to be sufficiently high so as to prevent undesired acoustic coupling due to an acoustic coupling agent such as ultrasound gel.

[0095] Referring to FIG. **11**, shown there generally as **1100** is a close-up perspective view of a pass-through volume component for the linear adapter in relation to an ultrasound probe, in accordance with at least one embodiment of the present invention. As noted, the pass-through volume **610** may be formed with a suitable acoustically-transparent material. In the embodiment of FIG. **11**, the pass-through volume **610** is formed with flanges **1105** that can adhere to the interior surface of the housing for the linear adapter **170'** (not shown in FIG. **11**) during assembly. FIG. **11** shows the pass-through volume component for the linear adapter **170'**.

[0096] As discussed above, the elevation length of the pass-through volume **610** and contact surface **174'** for the linear adapter **170'** is shorter than the traditional elevation length of the transducer elements on a traditional curvilinear ultrasound probe **100**. When the transducer adapters **170'** is attached to nose piece **104'** of ultrasound probe **100**, the proximal surface **120** of the pass-through volume **610** may be offset a distance from the interior surface of the linear transducer adapter **170'**. This offset **1115** distance may be chosen such that when an acoustic coupling agent (e.g., ultrasound gel) is interposed between the proximal surface **120** and the transducer, the pass-through volume **610** is acoustically coupled to the transducer while the volume adjacent the pass-through volume **610** is not acoustically coupled. For example, since using an acoustic coupling agent may allow for greater coupling between the transducer array and the pass-through volume **610**, application of the acoustic coupling agent to the proximal surface **120** may improve imaging when using the transducer adapter **170'**. However, once the transducer is positioned to be attached on the transducer adapter **170'**, it is possible that the acoustic coupling agent spills or bleeds over the edges of proximal surface **120** to occupy the volume adjacent the pass-through volume **120**. Configuring the offset distance **1115** to be sufficiently high may allow excess acoustic coupling agent to occupy a portion of the volume created by the offset distance **1115** while still maintaining an air gap between the transducer array and the flanges **1105** of the pass-through volume **610**. This may limit acoustic coupling to only the pass-through volume **610** and prevent acoustic coupling between the transducer array and the volume adjacent the pass-through volume **610**. Since such adjacent volume is intended to absorb/disperse ultrasound energy, the height **1115** may allow the desired slice thickness of the linear adapter **170'** to be achieved. This may also reduce unwanted image artifacts and improve image quality.

[0097] In this manner, the height of the offset distance **1115** may be configured to balance the desire to be as short as possible to minimize reverberation artifacts but still having enough height to prevent undesired acoustic coupling from the acoustic coupling agent. In various embodiments, the offset distance can be configured to be between 0-2.5 millimeters. However, other suitable offset distances may also be possible and are within the contemplation of the present embodiments.

[0098] Referring to FIG. **12**, shown there generally as **1200** is a flow chart depicting a method for generating an ultrasound image using a transducer adapter, according to at least one embodiment of the present invention. The method may be performed by ultrasound probe **100**. Additionally or alternatively, the method or parts thereof may be performed by a secondary device controlling the ultrasound probe, such as a multi-use electronic display device (not shown). In discussing the method of FIG. **12**, reference will simultaneously be made to the elements of FIGS. **1**, **3**, and **6** discussed above.

[0099] At **1210**, a transducer adapter **150**, **170** is coupled to ultrasound imaging transducer **100**. As described herein, the transducer adapter **150**, **170** may be coupled directly to the ultrasound probe **100**. As discussed, a coupling agent (e.g., ultrasound gel) may be interposed between transducer adapter **150**, **170** and ultrasound probe **100** to improve acoustic transmission between the two. The proximal surface of the pass-through volume **310**, **610** can be mated with the probe's transducer surface.

[0100] The geometry of the probe transducer surface may define a native footprint corresponding to its curvature and surface area. The distal surface of the transducer adapter **150**, **170**'s pass-through volume **310**, **610** may define an adapted footprint, representing a curvature and surface area different from the native footprint. Different types of probes **100** may have different footprints. For example, a cardiac probe may have a small footprint for cardiac imaging and a linear probe may have a linear, substantially planar footprint.

[0101] Different adapter types may be defined that mate with a particular footprint on its proximal end, and have a different adapted footprint on its distal end. For example, as discussed above, a cardiac adapter **150** for a curvilinear probe **100** may have a curvilinear proximal surface **120** to mate with the curvilinear transducer **100**, and a cardiac footprint on the distal surface **154** to contact an object being imaged. Similarly, a linear adapter **170** for a curvilinear probe **100** may have a curvilinear proximal surface **120** to mate with the curvilinear transducer **100**, and a linear footprint on the distal surface **174** to contact an object being imaged.

[0102] At **1220**, at least one ultrasound imaging parameter is modified. The imaging parameters may be modified so as to result in the ultrasound energy being emitted from (and received by) the adapted footprint of the distal contact surfaces **154**, **174** of the adapter **150**, **170** in a similar manner as the ultrasound energy would be emitted from and received by an ultrasound transducer with a native footprint that matches the adapted footprint.

[0103] For example, time delay and aperture may be modified as described in FIGS. **3** and **6** so that the ultrasound signals emitted by the ultrasound probe transducer are steered in a direction that is away from normal to the native footprint of the ultrasound transducer array. Whereas ultrasound signals generated from a curvilinear probe are traditionally transmitted and received sequentially from different apertures in directions normal to the probe's native footprint (e.g., in non-steered directions), FIGS. **3** and **6** above show how the ultrasound signals can be steered to provide ultrasound signals that are suitable for the contact surfaces **154**, **174** of the adapted footprints. For example, as shown in FIG. **3**, the apertures and time delays can be modified to steer ultrasound signals so that they are emitted and received in a phased manner similar to ultrasound signals traditionally emitted from a cardiac probe. Similarly, as shown in FIG. **6**, apertures and time delays can be configured so that ultrasound signals emitted from the ultrasound probe are not normal to the transducer array (at the aperture where the signals are being emitted from); but they exit the contact surface **174** in directions that is normal to the substantially planar footprint of the linear adapter **174** so as to yield parallel scanlines similar to those generated using a conventional linear ultrasound probe.

[0104] Depending on the transducer type, one or more of time delay, sequence, steering angle, transmit aperture size, transmit aperture location, receive aperture size, receive aperture location, and image zero point may be modified.

[0105] In some embodiments, the ultrasound imaging parameters can be modified based on the transducer adapter type. The adapter type may be considered to be based on at least one of a geometry of: the proximal end configured to mate to the ultrasound imaging transducer, and a geometry of the contact surface. Two example adapters have been discussed herein: an cardiac-type adapter **150** and a linear-type adapter **170**.

[0106] The transducer adapter type may be determined in several different ways. For example, an adapter type may be determined manually through input from the operator. This input may be through a selection made in software, or by actuating a physical switch on the ultrasound probe. For example, an operator may specify or choose an adapter type from a list of options in a user interface.

[0107] Additionally or alternatively, the adapter type may be determined automatically by the ultrasound probe. For example, the probe may include a sensor and the adapter may include a sensible element so that the probe can determine the adapter type. In various embodiments, this sensor could be based on radiofrequency identification (RFID), near-field communication (NFC), and/or other conventionally known or future developed sensing technologies.

[0108] Additionally or alternatively, the transducer adapter may include an image signature feature that enables the probe to detect adapter type using ultrasound image as described above and with reference to FIG. **13** below.

[0109] Referring back to FIG. **12**, at **1230**, an ultrasound image can be generated by ultrasound probe **100**. Depending on the adapter type, the generated ultrasound image may have different shapes. For example, with a linear-type adapter **170**, the image will be rectangular. In another example, the ultrasound image generated by the ultrasound probe with a cardiac-type adapter **150** attached will be sector-shaped.

[0110] Referring to FIG. **13**, shown there generally as **1300**, is an interior perspective view of an alternative embodiment of the cardiac adapter and linear adapter, in accordance with at least one embodiment of the present invention. As described above, the attached surface **120** is configured to mate to the transducer array of ultrasound probe **100**. In this embodiment, transducer adapter **150"**, **170"** includes an image signature feature **1356**, **1376**. As described above, image signature feature **1356**, **1376** may be configured to produce a characteristic image signature when transducer adapter **150"**, **170"** is coupled to ultrasound probe **100** and an ultrasound image is generated. The characteristic image signature produced by image signature feature **1356**, **1376** may be used by ultrasound probe **100** to determine the adapter type of the attached transducer adapter **150"**, **170"**.

[0111] As described above, image signature feature **1356**, **1376** may be constructed of the same material as the pass-through volume **310**, **610**, and/or may be constructed of a material that yields a characteristic signature, and/or may be constructed of the same material as the housing of the transducer adapter **150"**, **170"**. In various embodiments, the ultrasound probe **100** may differentiate between two different adapter types based on one or more of the following characteristics of the image signature feature **1356**, **1376**: echogenicity, feature width, and feature depth.

[0112] Referring to FIG. **14**, shown there generally as **1400**, is a cross-sectional view of the cardiac adapter and linear adapter of FIG. **13**, in accordance with at least one embodiment of the present invention. As shown, the attached surface **120** is mated to the transducer array of ultrasound probe **100**. Non-attached surfaces **154'**, **174'** form the distal end of the pass-through volumes similar to what was described with reference to the embodiments of FIG. **9**.

[0113] FIG. **14** shows a cross sectional view of image signature feature **1356**, **1376**. The image signature feature **1356**, **1376** is also configured to mate with the transducer **100** so that ultrasound signals may be projected to and reflected from it for the purpose of identifying the image signature features **1356**, **1376** on an ultrasound image. In various embodiments, there may be a gap between where attached surface **120** couples to the transducer **100** and where image signature feature **1356**, **1376** couples to the transducer array so that two separate sets of transducer elements are connected when the adapters **150"**, **170"** are attached. These separate transducer elements sets may be used by the probe to determine adapter type.

[0114] Referring to FIG. **15**, shown there generally as **1500**, is a diagram that shows the different imaging configurations of the ultrasound imaging probe and example cardiac and linear transducer adapters, in accordance with at least one embodiment of the present invention. A single ultrasound probe **100** may be used in several different configurations **100**A, **100**B, **100**C to image different parts of a patient or generate different types of ultrasound images.

[0115] Configuration **100**A shows ultrasound probe **100** with no transducer adapter attached. It may be operated in a conventionally-known manner to emit ultrasound signals **210** and generate an image **1510**A like that which is typically produced by a sequential curvilinear probe.

[0116] Configuration **100**B shows ultrasound probe **100** with a linear adapter **170'** attached. The substantially planar contact surface area of the adapted footprint for the linear adapter **170'** may enable the curvilinear ultrasound probe to couple more effectively to a substantially planar object that would otherwise require large amounts of coupling agent (e.g., ultrasound gel) or a forceful application of the ultrasound probe **100** onto the surface being imaged. Reducing the force required to effectively acoustically couple to the object being imaged may improve operator ergonomics and/or reduce tissue deformation that negatively affects image quality.

[0117] As noted, configuration **100**B may emit ultrasound signals **210** to generate a rectangular image **1510**B similar to a conventional ultrasound image generated by an ultrasound probe having a linear transducer geometry. As described with reference to FIG. **6-8** above, the steering of the ultrasound signals and reduced elevational length may generate an ultrasound image that shares other characteristics of a conventional linear ultrasound image, including consistent lateral resolution at various imaging depth, and improved elevational resolution.

[0118] Configuration **100**C show ultrasound probe **100** with a cardiac adapter **150'** attached. The smaller surface area of the adapted footprint of cardiac adapter **150'** may allow the operator to position the probe in a better position for imaging. For example, when imaging between the ribs, the smaller surface area of the adapted footprint may allow the contact surface to press further into the tissue between the patient's ribs, enabling a better image to be obtained. The smaller surface area of the adapted footprint may also mean that the operator need to exert less force, leading to less operator fatigue and better ergonomics.

[0119] As described with reference to FIG. **2-5** above, configuration **100**C may emit ultrasound signals **210** in a phased manner so as to generate a fan-shaped (e.g., sector) image **1510**C similar to the image generated by an ultrasound probe with a phased array transducer geometry.

[0120] As discussed above with respect to FIG. **3**, when the cardiac adapter **150** is attached, ultrasound signals **210** can be configured to exit the contact surface of the cardiac adapter so that the apex of the resultant sector image is at the non-attached surface **154** in the direction. However, in various embodiments, the apex of the sector image can be configured to be slightly higher (e.g., at the attached surface **120** of the cardiac adapter **150**, as shown in FIG. **1**). This may result in a sector image **1510**C that is slightly clipped at the top (e.g., show dotted lines in FIG. **15**). This type of clipped image may allow a substantial portion of a sector image to be provided and may be generated, for example, if the cardiac adapter **150** is attached to an ultrasound transducer **100** that is imaging in a sector imaging mode that is described in Applicant's Virtual Phased-array Application.

[0121] Using the embodiments described herein, an operator may quickly switch between configurations **100**A-C by detaching and attaching transducer adapters **150'**, **170'** to an ultrasound probe **100** as desired. While the description above refers to using ultrasound probe **100** with cardiac adapter **150'** and linear adapter **170'**, persons skilled in the art will recognize that just one type of transducer adapter may be used, or different types of transducer adapter may be used.

[0122] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize that may be certain modifications, permutations, additions and sub-combinations thereof. While the above description contains many details of example embodiments, these should not be construed as essential limitations on the scope of any embodiment. Many other ramifications and variations are possible within the teachings of the various embodiments.

Interpretation of Terms

[0123] Unless the context clearly requires otherwise, throughout the description and the claims:

- **[0124]** "comprise", "comprising", and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to";
- **[0125]** "connected", "coupled", or any variant thereof, means any connection or coupling, either direct or indirect, between two or more elements; the coupling or connection between the elements can be physical, logical, or a combination thereof;
- **[0126]** "herein", "above", "below", and words of similar import, when used to describe this specification, shall refer to this specification as a whole, and not to any particular portions of this specification;
- **[0127]** "or", in reference to a list of two or more items, covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list;
- **[0128]** the singular forms "a", "an", and "the" also include the meaning of any appropriate plural forms.
- **[0129]** Unless the context clearly requires otherwise, throughout the description and the claims:

[0130] Words that indicate directions such as "vertical", "transverse", "horizontal", "upward", "downward", "forward", "backward", "inward", "outward", "vertical", "transverse", "left", "right", "front", "back", "top", "bottom", "below", "above", "under", and the like, used in this description and any accompanying claims (where present), depend on the specific orientation of the apparatus described and illustrated. The subject matter described herein may assume various alternative orientations. Accordingly, these directional terms are not strictly defined and should not be interpreted narrowly.

[0131] Embodiments of the invention may be implemented using specifically designed hardware, configurable hardware, programmable data processors configured by the provision of software (which may optionally comprise "firmware") capable of executing on the data processors, special purpose computers or data processors that are specifically programmed, configured, or constructed to perform one or more steps in a method as explained in detail herein and/or combinations of two or more of these. Examples of specifically designed hardware are: logic circuits, application-specific integrated circuits ("ASICs"), large scale integrated circuits ("LSIs"), very large scale integrated circuits ("VLSIs"), and the like. Examples of configurable hardware are: one or more programmable logic devices such as programmable array logic ("PALs"), programmable logic arrays ("PLAs"), and field programmable gate arrays ("FPGAs"). Examples of programmable data processors are: microprocessors, digital signal processors ("DSPs"), embedded processors, graphics processors, math co-processors, general purpose computers, server computers, cloud computers, mainframe computers, computer workstations, and the like. For example, one or more data processors in a control circuit for a device may implement methods as described herein by executing software instructions in a program memory accessible to the processors.

[0132] For example, while processes or blocks are presented in a given order herein, alternative examples may perform routines having steps, or employ systems having blocks, in a different order, and some processes or blocks may be deleted, moved, added, subdivided, combined, and/or modified to provide alternative or subcombinations. Each of these processes or blocks may be implemented in a variety of different ways. Also, while processes or blocks are at times shown as being performed in series, these processes or blocks may instead be performed in parallel, or may be performed at different times.

[0133] The invention may also be provided in the form of a program product. The program product may comprise any non-transitory medium which carries a set of computer-readable instructions which, when executed by a data processor (e.g., in a controller and/or ultrasound processor in an ultrasound machine), cause the data processor to execute a method of the invention. Program products according to the invention may be in any of a wide variety of forms. The program product may comprise, for example, non-transitory media such as magnetic data storage media including floppy diskettes, hard disk drives, optical data storage media including CD ROMs, DVDs, electronic data storage media including ROMs, flash RAM, EPROMs, hardwired or preprogrammed chips (e.g., EEPROM semiconductor chips), nanotechnology memory, or the like. The computer-readable signals on the program product may optionally be compressed or encrypted.

[0134] Where a component (e.g. an adapter, a software module, processor, assembly, device, circuit, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0135] Specific examples of systems, methods and apparatus have been described herein for purposes of illustration. These are only examples. The technology provided herein can be applied to systems other than the example systems described above. Many alterations, modifications, additions, omissions, and permutations are possible within the practice of this invention. This invention includes variations on described embodiments that would be apparent to the skilled addressee, including variations obtained by: replacing features, elements and/or acts with equivalent features, elements and/or acts; mixing and matching of features, elements and/or acts from different embodiments; combining features, elements and/or acts from embodiments as described herein with features, elements and/or acts of other technology; and/or omitting combining features, elements and/or acts from described embodiments.

[0136] It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions, omissions, and sub-combinations as may reasonably be inferred. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

What is claimed is:

1. An ultrasound imaging transducer assembly, comprising:

an ultrasound imaging transducer having transducer elements configured in a curved geometry; and

a transducer adapter for coupling to the ultrasound imaging transducer, wherein the transducer adapter comprises a pass-through volume for permitting ultrasound energy to be transmitted through the transducer adapter, the pass-through volume comprising:

a proximal surface for mating to the transducer, the proximal surface having a curvature corresponding to the curved geometry of the transducer elements; and

a distal surface at a distal end of the transducer assembly, the distal surface having a geometry that is substantially planar.

2. The ultrasound imaging transducer assembly of claim **1**, wherein the ultrasound imaging transducer is configured to determine an adapter type of the transducer adapter.

3. The ultrasound imaging transducer assembly of claim **2**, wherein the ultrasound imaging transducer further comprises a sensor for determining the adapter type of the transducer adapter.

4. The ultrasound imaging transducer assembly of claim **3**, wherein the transducer adapter includes a radio frequency identification (RFID) tag and the sensor comprises a radio frequency identification (RFID) sensor.

5. The ultrasound imaging transducer assembly of claim **1**, wherein the transducer adapter further comprises an image signature feature readable by the ultrasound imaging transducer when the transducer adapter is coupled to the ultrasound imaging transducer.

6. The ultrasound imaging transducer assembly of claim **1**, wherein the pass-through volume comprises at least one of agar, agarose, Aqualene™, silicone, polyvinyl alcohol, polyvinyl alcohol gel, polyacrylamide gel, open porosity foam, gelatin gel, oil gel, polyurethane gel, epoxy plastisol, silicon rubber, swollen segmented polyurethane gel (S-SPUG), urethane polymer, tofu, magnesium silicate, and Zerdine™.

7. The ultrasound imaging transducer assembly of claim **1**, wherein the ultrasound transducer elements have a first elevational length and the proximal surface has a second elevational length, different from the first elevational length.

8. A method of generating ultrasound images with an ultrasound imaging transducer, the ultrasound imaging transducer having a native footprint, the method comprising:

coupling a transducer adapter to the ultrasound imaging transducer, wherein the transducer adapter has a proximal end configured to mate to the ultrasound imaging transducer and a distal end that defines a contact surface, wherein the contact surface corresponds to an adapted footprint different from the native footprint;

modifying at least one imaging parameter so that, during imaging, ultrasound signals emitted from the ultrasound imaging transducer travels through the transducer adapter and exits the contact surface, and the exiting ultrasound signals have one or more characteristics substantially similar to other ultrasound signals emitted from another ultrasound imaging transducer having the adapted footprint as its native footprint; and

generating the ultrasound images with the modified at least one imaging parameter.

9. The method of claim **8**, wherein after the transducer adapter is coupled, the modified at least one imaging parameter causes the at least one of the ultrasound signals emitted from the ultrasound imaging transducer to be steered in a direction away from normal to the native footprint of the ultrasound imaging transducer.

10. The method of claim **9**, wherein prior to the transducer adapter being coupled, during imaging, the ultrasound imaging transducer emits non-steered ultrasound signals.

11. The method of claim **9**, wherein the modified at least one imaging parameter comprises at least one of time delay and aperture, to cause the at least one of the ultrasound signals to be steered in the direction away from normal to the native footprint of the ultrasound imaging transducer.

12. The method of claim **9**, wherein the adapted footprint comprises a cardiac footprint, and wherein the exiting ultrasound signals are steered in respective different directions so that a substantial portion of a sector image is generated.

13. The method of claim **9**, wherein the adapted footprint comprises a linear footprint, and wherein the steered at least one of the ultrasound signals emitted from the ultrasound imaging transducer results in the exiting ultrasound signals being projected orthogonally to the contact surface.

14. The method of claim **13**, wherein the exiting ultrasound signals comprise parallel ultrasound signals so that a rectangular image is generated.

15. The method of claim **8**, further comprising, after coupling the transducer adapter:

determining an adapter type of the transducer adapter, wherein the adapter type is based on at least one of a geometry of: the proximal end configured to mate to the ultrasound imaging transducer, and a geometry of the contact surface.

16. The method of claim **15**, wherein the modifying of the at least one imaging parameter is based at least in part on the adapter type.

17. The method of claim **16**, wherein the ultrasound imaging transducer further comprises a sensor and wherein the determining the adapter type of the transducer adapter comprises:

sensing the adapter type of the transducer adapter using the sensor.

18. The method of claim **15**, wherein an image signature feature is provided on the transducer adapter that is readable when the transducer adapter is coupled to ultrasound imaging transducer, and the determining the adapter type of the transducer adapter comprises:

generating an ultrasound image; and

identifying the image signature feature on the ultrasound image to determine the adapter type of the transducer adapter.

19. A transducer adapter for coupling to an ultrasound imaging transducer with a native footprint, the transducer adapter comprising:

a proximal end configured to mate to the ultrasound imaging transducer; and

a distal end that defines a contact surface, wherein the contact surface corresponds to an adapted footprint different from the native footprint;

wherein when the transducer is coupled to the ultrasound imaging transducer, ultrasound signals emitted from the ultrasound imaging transducer travels through the transducer adapter and exits the contact surface, and the exiting ultrasound signals have one or more characteristics that are substantially similar to ultrasound signals emitted from another ultrasound imaging transducer having the adapted footprint as its native footprint.

20. The transducer adapter of claim **19**, wherein the transducer adapter comprises a pass-through volume for permitting the ultrasound signals to be transmitted through the transducer adapter.

21. The transducer adapter of claim **20**, wherein the pass-through volume comprises at least one of agar, agarose, Aqualene™, silicone, polyvinyl alcohol, polyvinyl alcohol gel, polyacrylamide gel, open porosity foam, gelatin gel, oil gel, polyurethane gel, epoxy plastisol, silicon rubber, swollen segmented polyurethane gel (S-SPUG), urethane polymer, tofu, magnesium silicate, and Zerdine™.

22. The transducer adapter of claim **19**, wherein the transducer adapter further comprises an image signature feature readable by the ultrasound imaging transducer when the transducer adapter is coupled to the ultrasound imaging transducer.

* * * * *

patsnap

专利名称(译)	传感器适配器，允许使用单个超声换能器进行多种超声成像模式		
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[标]申请(专利权)人(译)	CLARIUS移动医疗		
申请(专利权)人(译)	Clarius移动健康公司		
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摘要(译)

本实施例一般涉及超声成像系统。超声成像系统可包括：超声成像换能器，可操作以获取超声图像数据;以及换能器适配器，被配置为可拆卸地耦合到超声成像换能器。换能器适配器可以提供与超声成像换能器本机覆盖区不同的覆盖区，以使超声成像换能器适配器能够以与具有不同换能器几何形状的超声换能器基本相似的方式采集超声图像数据。超声成像换能器可包括用于检测换能器适配器的附接状态的传感器。当换能器附接到超声成像换能器时，超声成像换能器可以修改一个或多个成像参数。