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(54) Title: ASYMMETRIC PHASED-ARRAY ULTRASOUND TRANSDUCER

(57) Abstract: An asymmetric ultrasound transducer array may include multiple regions or groups of transducer elements. The regions may be configured to generate respective ultrasound beams with different capabilities, such as, e.g., focusing at varying focal depths and lateral steering, and/or focusing into different volumes.

## ASYMMETRIC PHASED-ARRAY ULTRASOUND TRANSDUCERS

### CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of, and incorporates herein by reference in its entirety, U.S. Provisional Patent Application No. 61/237,054, which was filed on August 26, 2009.

### FIELD OF THE INVENTION

5 [0002] The present invention relates generally to phased-array ultrasound transducer systems and methods of using same, and more specifically to asymmetric transducer configurations for application-specific ultrasound delivery.

### BACKGROUND

[0003] Focused ultrasound (i.e., acoustic waves having a frequency greater than about 20  
10 kilohertz) can be used to image internal body tissues or, at high intensity, to generate thermal ablation energy to treat tissue such as tumors. By way of illustration, FIG. 1 is a simplified schematic representation of an exemplary focused ultrasound system 100 used to generate and deliver a focused acoustic energy beam 102 to a targeted tissue mass 104 in a patient 106. The system 100 employs an ultrasound transducer 108 that is geometrically shaped and physically  
15 positioned relative to the patient 106 in order to focus the ultrasonic energy beam 102 at a three-dimensional focal zone located within the targeted tissue mass 104. The transducer 108 may be substantially rigid, semi-rigid, or substantially flexible, and can be made from a variety of materials, such as plastics, polymers, metals, and alloys. The transducer 108 can be manufactured as a single unit, or, alternatively, be assembled from a plurality of components.  
20 While the illustrated transducer 108 has a “spherical cap” shape, a variety of other geometric shapes and configurations may be employed to deliver a focused acoustic beam, including other non-planar as well as planar (or linear) configurations. The dimensions of the transducer may vary, depending on the application, between millimeters and tens of centimeters.

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[0004] The transducer 108 may include a large number of transducer elements 110, arranged in a one- or two-dimensional array or other regular manner, or in an uncoordinated fashion. These elements 110 convert electronic drive signals into mechanical motion and, as a result, into acoustic waves. They may be made, for example, of piezoelectric ceramics or piezo-composite materials, and may be mounted in silicone rubber or another material suitable for damping the mechanical coupling between the elements 110. The transducer elements 110 are connected via electronic drive signal channels 112 to a control module 114, which drives the individual transducer elements 110 so that they collectively produce a focused ultrasonic beam. More specifically, the control module 114 may include a beamformer 116 that sets the relative amplitudes and phases of the drive signals in channels 112. In conventional focused ultrasound systems containing  $n$  transducer elements, the beamformer 116 typically contains  $n$  amplifiers 118 and  $n$  phase control circuits 120, each pair driving one of the transducer elements 110. The beamformer 116 receives a radio frequency (RF) input signal, typically in the range from 0.1 MHz to 3 MHz, from frequency generator 122. The input signal may be split into  $n$  channels for the  $n$  amplifiers and phase circuits 118, 120 of the beamformer 116. Thus, in typical conventional systems, the radio frequency generator 122 and the beamformer 116 are configured to drive the individual elements 110 of the transducer 108 at the same frequency, but at different phases and different amplitudes, such that the transducer elements 110 collectively form a “phased array.”

[0005] The acoustic waves transmitted from the transducer elements 110 form the acoustic energy beam 102. Typically, the transducer elements are driven so that the waves converge at a focal zone in the targeted tissue mass 104. Within the focal zone, the wave energy of the beam 102 is (at least partially) absorbed by the tissue, thereby generating heat and raising the temperature of the tissue to a point where the cells are denatured and/or ablated. The location, shape, and intensity of the focal zone of the acoustic beam 102 is determined, at least in part, by the physical arrangement of the transducer elements 110, the physical positioning of the transducer 108 relative to the patient 106, the structure and acoustic material properties of the tissues along the beam path between the transducer 108 and the target tissue 104, and the relative phases and/or amplitudes of the drive signals. Setting the drive signals so as to focus the acoustic energy at a desired location is a process known as “electronic steering” of the beam 102. The amplification or attenuation factors  $\alpha$  and the phase shifts  $\phi$  imposed by the

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beamformer 116 and used to steer the beam are computed in a controller 124, which may provide the computational functions through software, hardware, firmware, hardwiring, or any combination thereof. For example, the controller 124 may utilize a special-purpose digital signal processor or a general-purpose computer programmed with software in a conventional manner. In certain embodiments, the computation is based on image data obtained with a magnetic resonance imaging (MRI) apparatus or other imager (not shown). Further, the controller 124 may be in communication with a user interface 126 that facilitates the selection of the focus location or other treatment parameters.

**[0006]** Phased-array transducers provide the greatest beam-steering capability when each transducer element 110 can be controlled independently through a separate drive signal channel 112, as illustrated in FIG. 1. This flexibility comes, however, at a price, as large numbers of electronic channels are costly. Thus, as the number of elements increases, the ability to drive them independently becomes concomitantly less practical for complexity and cost reasons. To curtail cost increases resulting from larger numbers of transducer elements, many applications exploit system symmetries to drive multiple elements with a single channel. An axis of symmetry may be defined, for example, by the direction of the acoustic beam propagation when all elements of the array are driven in phase. The transducer elements may be connected to (a smaller number of) drive signal channels in a way that reflects, for example, a corresponding radial symmetry around the intersection of this axis with the transducer surface. Such symmetric transducers achieve a reasonable trade-off between high steering capability along one axis (e.g., steering of the focal length at the cost of very limited lateral steering, or vice versa) and low system complexity in many applications. However, they are unduly limiting when the transducer cannot be freely moved, e.g., as a consequence of certain anatomical barriers. Accordingly, there is a need for accommodating large numbers of small transducer elements in any array without the burden of separately driving them, but also without sacrificing the beam focusing and steering capabilities needed in specific clinical applications.

### SUMMARY

[0007] The present invention relates to ultrasound transducer systems and ultrasound focusing methods that provide sufficient beam-focusing and steering flexibility to accommodate many clinical applications, yet avoid the need to individually control large numbers of transducer elements. In various embodiments, the transducer surface is formed by an isotropic array of transducer elements, each of which receives a drive signal through an electronic signal channel. The transducer elements are sufficiently small and numerous to provide for high beam steerability. To keep system complexity and cost low, however, the transducer elements are grouped, and the elements in each group are driven together so as to limit the total number of independent drive signal channels needed to control the entire array. While the grouping of transducer elements may be hard-wired for certain categories of applications, preferred embodiments accomplish the grouping dynamically, thereby allowing groupings to be adjusted to a particular treatment scenario (e.g., a particular patient anatomy and arrangement of the treatment equipment). For example, an additional layer of switches may be connected to the transducer elements, and based on an analysis of the treatment scenario, these switches may be set so as to define a plurality of transducer-element groups.

[0008] In various embodiments, the configuration of the phased-array transducer is asymmetric (e.g., with respect to the beam propagation axis). The grouping of transducer elements may result in two or more transducer regions tailored for particular functions, each including at least one, but typically several, groups of elements. For example, one region may be designed for depth focusing, and another region for lateral beam steering. The different regions may be driven independently or, alternatively, simultaneously to adjust the acoustic beam focusing and steering properties to a specific application. Due to the complementary functionalities of the transducer regions, the transducer array maintains a high degree of flexibility without requiring overly complex controlling mechanisms. In particular, certain embodiments of the invention allow focusing ultrasound into treatment areas which, due to their proximity to anatomical barriers, would not be readily accessible with a symmetric transducer array.

[0009] Accordingly, in a first aspect, the invention provides an asymmetric ultrasound transducer with a plurality of ultrasound transducer elements arranged in a two-dimensional (planar or non-planar) phased array including first and second regions. A first plurality of

signal channels is connected to and collectively drives the transducer elements of the first region so as to generate a first ultrasound beam and to facilitate focusing that beam at varying focal depths along a focal path in the direction of beam propagation. A second plurality of signal channels is connected to and collectively drives the transducer elements of the second region so as to generate a second ultrasound beam and to facilitate lateral steering of that beam in a direction perpendicular to beam propagation. In certain embodiments, at least some of the signal channels of each of the first and second pluralities of channels are connected to multiple transducer elements of the first region and the second region, respectively. The first region may facilitate focusing the first ultrasound beam at a tissue depth beneath a patient's skin line of less than 4 cm. The second ultrasound beam may have a steerability greater than 1 radian. In some embodiments, the first and second regions are configured to facilitate steering of the first and second ultrasound beams into first and second selected volumes, respectively. When both regions are operated simultaneously, they may generate a third ultrasound beam and facilitate steering the third ultrasound beam into a third volume that is not entirely within the first and second volumes.

**[0010]** In a second aspect, an asymmetric ultrasound transducer in accordance with various embodiments includes a plurality of ultrasound transducer elements arranged in a two-dimensional (planar or non-planar) phased array, each transducer element having a switch associated with it; a plurality of signal channels connected to the transducer elements via the switches such that at least some of the signal channels are connected to multiple transducer elements; and a controller configuring the switches so as to group the transducer elements. The controller, in grouping transducer elements, forms a first region of the transducer that is capable of focusing at varying focal depths along a focal path in the direction of beam propagation, and a second region that is capable of lateral beam steering (i.e., beam steering in a direction perpendicular to beam propagation). The first and second regions may facilitate beam steering into first and second volumes, respectively.

**[0011]** In a third aspect, the invention provides an asymmetric ultrasound transducer system comprising a plurality of ultrasound transducer elements with associated switches, arranged in a two-dimensional phased array; a plurality of signal channels connected to the transducer elements via the switches; a controller for configuring the switches; means for storing data sets each corresponding to a configuration of the switches; and means facilitating user selection of one of the stored data sets, the controller being responsive to the selection and configuring the

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switches in accordance therewith. In some embodiments, at least one of the data sets specifies one or more regions of grouped transducer elements capable of shallow focusing and one or more regions of grouped transducer elements capable of lateral beam steering. Further, in some embodiments, at least one of the data sets specifies one or more regions capable of steering an  
5 ultrasound beam into a selected volume. In some embodiments, at least one of the data sets specifies one or more regions of grouped transducer elements capable of focusing at varying focal depths along a focal path in the direction of beam propagation and one or more regions of grouped transducer elements capable of lateral beam steering.

**[0012]** In a fourth aspect, a method of configuring an asymmetric ultrasound transducer is  
10 provided. The method includes providing a plurality of ultrasound transducer elements arranged in a (planar or non-planar) two-dimensional phased array; dynamically configuring a plurality of signal channels connected to the transducer elements in response to geometric constraints associated with a patient's anatomy and an equipment configuration, thereby producing a plurality of groups of transducer elements; and separately driving the groups of  
15 transducer elements. The signal channels may be configured so as to form first and second regions of grouped transducer elements. In some embodiments, the first and second regions are capable of focusing at varying focal depths along a focal path in the direction of beam propagation and of lateral beam steering, respectively. In some embodiments, the first and second regions are capable of beam steering into first and second volumes, respectively.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0013]** The foregoing will be more readily understood from the following detailed description, in particular, when taken in conjunction with the drawings, in which:

**[0014]** FIG. 1 is a schematic drawing illustrating a focused ultrasound system with independently controllable transducer elements;

**[0015]** FIG. 2 is a schematic drawing illustrating a focused ultrasound system in  
25 accordance with various embodiments in which transducer elements are grouped;

**[0016]** FIG. 3 is a schematic drawing illustrating a transducer-array configuration in accordance with one embodiment;

**[0017]** FIG. 4 is a schematic drawing illustrating a treatment scenario in which focused  
30 ultrasound systems in accordance with various embodiments can advantageously be used; and

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[0018] FIG. 5 is a schematic drawing illustrating a focused ultrasound system in accordance with various embodiments in which transducer elements are variably grouped.

### DESCRIPTION

[0019] Phased-array ultrasound transducers in accordance with various embodiments of the invention enable three-dimensional beam steering, i.e., steering of both the depth of focus and the lateral focus position, over a large volume. Typically, the transducer includes a large number (e.g., hundreds or thousands) of individual transducer elements whose linear dimensions are no greater than the wavelength of the acoustic waves generated during operation. Preferably, the largest dimension of each element is equal to or smaller than half the acoustic wavelength. Using small transducer elements results in high steerability of the acoustic beam. For example, with transducer element dimensions of no more than half a wavelength, the steering angle (i.e, the maximum angle with respect to the normal of the transducer surface that can be achieved) in each direction is  $\pm\pi/2$ , which facilitates covering a complete hemisphere. In certain embodiments, the transducer elements are of uniform size and shape and are evenly arranged (e.g., in a tiled fashion) so as to form an isotropic array.

[0020] The elements of the transducer array are driven via electronic signals by a control facility. To keep complexity and cost low, the transducer elements may be grouped, and elements within each group wired together so as to receive a drive signal from a single channel. As a consequence, the number of channels may be significantly smaller than the number of transducer elements. An exemplary implementation of such an ultrasound focusing system is conceptually illustrated in FIG. 2A. In the depicted system 200, each element 110 of the ultrasound transducer 118 is connected to an amplifier 118 and phase control circuit 120 via a drive signal channel 112. However, the number of drive signal channels 112 is smaller than the number of transducer elements 110, since at least some of the signal channels 112 are each connected to more than one transducer element 110. As a result, the complexity of the beamformer 202 is reduced (compared with that of a beamformer in a conventional system in which every element is separately controllable).

[0021] The elements within each group may form a single contiguous area of the transducer surface, or include multiple non-contiguous surface portions. The grouping of elements may follow different design criteria for various regions of the transducer, and may be adjusted to the functional requirements of the regions. For example, one region may be wired to generate an



acoustic beam with a relatively shallow focal depth. For the purposes of most clinical applications, depths in the tissue between the skin line and up to about 2-3 cm deep are considered shallow. Another region may be optimized for lateral steering. Using both of these regions in combination, medium and deep focusing (e.g., up to 6 cm for 2 to 3 MHz) may be achieved. In another embodiment, two regions may be configured to accommodate a range of focal depths and a range of lateral focus positions at a predetermined depth, respectively. Further, different regions may be designed to generate focused acoustic beams covering different volumes in space. If some or all of the regions are driven simultaneously, additional volumes in space may be accessed with the same transducer array, in many cases, in a single sonication. Certain embodiments provide increased beam steering performance within a specified volume by enabling one or more regions of the transducer surface to be used alone while transducer elements in the remaining region(s) are either turned off or driven at amplitudes that are so low that they make only negligible contributions to the total focused energy, or generate a focus at a different place in the target. When the various regions are driven together, on the other hand, the combined ultrasound beam can be focused at a depth where, using only part of the total transducer area, the focus size will be too big. Regions of the transducer array that are designed for different functions may benefit from different operating frequencies. Therefore, in various embodiments, a frequency generator 204 with multiple frequency channels 206 (or, alternatively, a plurality of frequency generators each having one or more channels) may be used to provide the beamformer 202 with two or more input frequencies for the various drive signal channels 112. Typically, the number of frequency channels 206 is smaller than the number of drive signal channels 112. The frequencies provided to the beamformer 202 may be set by the controller 124, which also controls the amplifier and phase circuits 118, 120. The drive signal and acoustic beam frequencies generally vary between about 0.1 MHz and about 3 MHz. A region of the array intended for shallow focusing uses higher frequencies (e.g., frequencies of at least 1.5MHz) to reduce focus size and to increase the absorption of acoustic energy. A region intended for lateral steering, on the other hand, uses lower frequencies to reduce the ratio of transducer elements size to wavelength to improve the angular response of the transducer. When the entire transducer is used, the deeper into the body the beam is to be focused, the lower the selected frequency will generally be.

[0022] The individual regions of the array may, but need not, be wired symmetrically to minimize the complexity of the beam former, whereas the transducer as a whole is typically wired asymmetrically to enable different regions of the transducer to cover different volumes. In contrast to symmetric signal channel configurations, which usually involve a trade-off  
5 between focal-depth steerability and lateral steerability, asymmetric configurations enable the transducer to accommodate both focal-depth steering and lateral steering requirements. Further, such a design may be better adjusted to the treatment of certain areas of the human anatomy that are themselves highly asymmetrical

[0023] FIG. 3 schematically illustrates an exemplary transducer 300 in accordance with one  
10 embodiment. The transducer is formed by about three thousand transducer elements whose center points (corresponding to the individual points shown in FIG. 3) are arranged equidistantly from each other at lattice points within a rectangular lattice. Such a lattice may be produced, for example, by etching or sawing the discrete transducer elements from a continuous sheet, which results in a tiled arrangement of uniformly sized elements with sub-  
15 wavelength dimensions (in the illustrated embodiment, approximately 1 mm). Alternatively, the transducer elements may be manufactured separately and afterwards placed onto a supporting surface. The transducer elements may, generally, vary in size and shape, and may be arranged in a planar or a non-planar array. They are wired to form about 1200 groups of elements (illustrated by lines connecting the points in FIG. 3), each group being driven by an  
20 associated signal channel. In this one particular embodiment, the transducer 300 is configured into three regions. The first region 302 is designed for lateral steering along the long axis 304 of the transducer array (i.e., left/right). Most of its elements are grouped in a direction perpendicular to that axis, with smaller groupings of four elements flanking the boundaries of the array. The center region 306 has planar steering capabilities, enabling steering along both  
25 axes of the transducer array (i.e., left/right and up/down). In this region 306, transducer elements are grouped in pairs. Finally, the third region 308, which encompasses half of the transducer area, is optimized for depth focusing around the geometrical center 310 of the transducer. The groupings of transducer elements in this region 308 are substantially radially symmetric about the geometrical center

[0024] An asymmetric transducer with different functional regions (such as transducer 300)  
30 may be used in medical applications where the transducer cannot be arbitrarily moved and tilted with respect to the patient or target tissue. Such a situation may arise due to anatomical

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barriers or obstacles posed by the particular configuration of treatment equipment. Anatomical barriers, as the term is used herein, may be determined by both physical barriers to the movement of the transducer, as well as by changes in acoustic properties along the beam path due to interfaces between different materials (e.g., air, bone etc.) that will cause reflection or absorption of the acoustic beam. Treatment equipment includes the ultrasound transducer system itself, as well as other equipment that may simultaneously be needed (such as, e.g., an MRI imaging apparatus) and whose locations and space requirements may further restrict the movability of the transducer.

**[0025]** FIG. 4 schematically illustrates a treatment scenario in which an anatomical barrier 402 diminishes the portion of a target tissue 404 that can be reached by the ultrasound beam 406. As shown, the anatomical barrier 402 prevents the transducer 408 from being shifted further toward the left in this illustration. A conventional symmetric transducer that focuses ultrasound along a symmetry axis 410 might therefore not be able to reach a region 412, which is located close to the barrier 402. An asymmetric transducer, on the other hand, may be able to overcome the anatomical barrier 402 by beam steering. To accommodate the illustrated constraints, the transducer 408 should be configured to allow significant electronic steering toward the left side to overcome the anatomical barrier 402. The right side requires less steering capability, thereby reducing the required number of independently controllable elements in that region, and, thus, allowing elements to be grouped. The transducer array as a whole preferably provides a large dynamic range of focusing (from shallow focal depth to deep focusing). The transducer array 300 illustrated in FIG. 3 substantially satisfies these requirements, and is therefore suitable for use in the scenario shown in FIG. 4.

**[0026]** In various preferred embodiments, transducer element groupings are not hard-wired, but can be set dynamically to accommodate a variety of treatment scenarios. FIG. 5 illustrates a system that facilitates dynamic groupings by incorporating a layer of switches 502 between the transducer array 108 and the beamformer 202. Via the switches, each transducer element 110 can be connected variably with one of the drive signal channels 112 associated with amplifier and phase control components 118, 120. For example, in the depicted system, the switches have three settings, corresponding to three independent drive signals. (In practice, the number of switch positions and drive channels is typically much larger.) Although switches that facilitate the connection of each transducer element 110 to each drive signal channel 112 provide the greatest degree of flexibility for a given number of elements 110 and channels 112,

embodiments of the invention also encompass systems with fewer switch settings, i.e., systems in which the individual transducer elements 110 can only be connected to a subset of signal channels 112. For example, the switches may facilitate selection only between channels that receive the same input frequency from frequency generator 204. Further, in place of simple switches, other channel selection means (such as “cascades” — i.e., multiple layers of serially connected — switches) may be used. In some embodiments, an additional layer of switches (not shown) between the frequency generator 204 and the beamformer 202 facilitates variably connecting the drive signal channels 112 to various frequency channels.

**[0027]** The switches 502 (or alternative channel selection means) that connect the transducer elements to the drive signal channels, as well as any switches for frequency selection, may be set by the controller 504. The controller may, in turn, receive information about the switch settings from a user through the user interface 126. In some embodiments, the controller includes logic or software for computing preferred switch settings based on anatomical barriers and other physical obstacles that may limit movement of the transducer, as well as the beam focus requirements for a particular application. For example, an optimization algorithm may take this information, along with parameters characterizing the transducer array (including, for example, the number, size, shape, and density of elements in the array), as input to produce an optimal grouping pattern and/or determine optimal drive frequencies for each group. The relationship of groupings and relative phase-settings of transducer elements to the resulting steerability of the beam may then be modeled analytically. Thus, the controller facilitates the dynamic adjustment and configuration of elements within the transducer system based on a particular clinical application and a particular desired location of the focus within the anatomy.

**[0028]** In some embodiments of the invention, the element groupings may be determined in advance rather than in a clinical setting. For example, a small number of paradigmatic groupings and driving parameters may be designed that address a significant number of possible treatment regimens, and data representative of these groupings may be stored for future use. The data may be stored, for example, on a hard drive of the controller 504, or on a separate storage unit in communication with the controller 504. The data may specify the number of transducer regions, the element groupings for each region, frequency constraints for each region or group, as well as other operational parameters of the transducers. Any of the stored data sets may be invoked in the clinical setting, when it is determined which

configuration is most appropriate given condition to be treated and/or the physical constraints of the treatment regimen. In such cases, a clinician may select the desired configuration, e.g., using the interface 126, and the controller 504 retrieves the data and configures and drives the transducer system accordingly. If the stored configurations are sufficient to cover most  
5 situations encountered in a clinical setting, the need for patient-specific configuration may be eliminated or confined to fine-tuning of a selected configuration.

**[0029]** Having described certain embodiments of the invention, it will be apparent to those of ordinary skill in the art that other embodiments incorporating the concepts disclosed herein may be used without departing from the spirit and scope of the invention. Accordingly, the  
10 described embodiments are to be considered in all respects as only illustrative and not restrictive.

**[0030]** What is claimed is:

**CLAIMS**

- 1 1. An asymmetric ultrasound transducer, comprising:  
2 (a) a plurality of ultrasound transducer elements arranged in a two-dimensional phased  
3 array comprising at least a first region and a second region;  
4 (b) a first plurality of signal channels connected to and collectively driving the  
5 transducer elements of the first region so as to generate a first ultrasound beam; and  
6 (c) a second plurality of signal channels connected to and collectively driving the  
7 transducer elements of the second region so as to generate a second ultrasound beam,  
8 wherein the first region facilitates focusing the first ultrasound beam at varying focal  
9 depths along a focal path in the direction of beam propagation and the second region facilitates  
10 lateral steering of the second ultrasound beam in a direction perpendicular to beam propagation.
- 1 2. The asymmetric ultrasound transducer of claim 1, wherein the two-dimensional phased  
2 array is planar.
- 1 3. The asymmetric ultrasound transducer of claim 1, wherein the two-dimensional phased  
2 array is non-planar.
- 1 4. The asymmetric ultrasound transducer of claim 1, wherein the first region is configured  
2 to facilitate steering of the first ultrasound beam into a first selected volume and the second  
3 region is configured to facilitate steering of the second ultrasound beam into a second selected  
4 volume.
- 1 5. The asymmetric ultrasound transducer of claim 4, wherein the first and second regions,  
2 when operated simultaneously, generate a third ultrasound beam and facilitate steering the third  
3 beam into a third volume not entirely within the first and second volumes.
- 1 6. The asymmetric ultrasound transducer of claim 1, wherein the first region facilitates  
2 focusing the first ultrasound beam at a tissue depth beneath a patient's skin line of less than 4  
3 cm.
- 1 7. The asymmetric ultrasound transducer of claim 1, wherein the second ultrasound beam  
2 has a lateral steerability greater than 0.1 radians.

- 1 8. The system of claim 1, wherein at least some of the signal channels of the first plurality  
2 are connected to multiple transducer elements of the first region, and at least some of the signal  
3 channels of the second plurality are connected to multiple transducer elements of the second  
4 region.
- 1 9. An asymmetric ultrasound transducer, comprising:  
2 (a) a plurality of ultrasound transducer elements arranged in a two-dimensional phased  
3 array, each transducer element having at least one switch associated therewith;  
4 (b) a plurality of signal channels connected to the transducer elements via the switches,  
5 at least some of the signal channels being connected to multiple transducer elements; and  
6 (c) a controller configuring the switches so as to group the transducer elements, thereby  
7 forming first and second regions of grouped transducer elements, the first region capable of  
8 focusing at varying focal depths along a focal path in the direction of beam propagation and the  
9 second region capable of lateral beam steering in a direction perpendicular to beam  
10 propagation.
- 1 10. The asymmetric ultrasound transducer of claim 9, wherein the two-dimensional phased  
2 array is planar.
- 1 11. The asymmetric ultrasound transducer of claim 9, wherein the two-dimensional phased  
2 array is non-planar.
- 1 12. The asymmetric ultrasound transducer of claim 9, wherein the first region is configured  
2 to facilitate beam steering into a first selected volume and the second region is configured to  
3 facilitate beam steering into a second selected volume.
- 1 13. An ultrasound transducer system, comprising:  
2 (a) a plurality of ultrasound transducer elements arranged in a two-dimensional phased  
3 array, each transducer element having at least one switch associated therewith;  
4 (b) a plurality of signal channels connected to the transducer elements via the switches;  
5 (c) a controller configuring the switches so as to group the transducer elements;  
6 (d) means for storing data sets each corresponding to a configuration of the switches;  
7 and  
8 (e) means facilitating user selection of one of the stored data sets, the controller being  
9 responsive to the selection and configuring the switches in accordance therewith.

1 14. The system of claim 13 wherein at least one of the data sets specifies at least one region  
2 of grouped transducer elements capable of shallow focusing and at least one region of grouped  
3 transducer elements capable of lateral beam steering.

1 15. The system of claim 13 wherein at least one of the data sets specifies at least one region  
2 of grouped transducer elements capable of steering an ultrasound beam into a selected volume.

1 16. The system of claim 13 wherein at least one of the data sets specifies at least one region  
2 of grouped transducer elements capable of focusing at varying focal depths along a focal path  
3 in the direction of beam propagation and at least one region of grouped transducer elements  
4 capable of lateral beam steering.

1 17. A method of configuring an asymmetric ultrasound transducer, the method comprising:

2 (a) providing a plurality of ultrasound transducer elements arranged in a two-  
3 dimensional phased array;

4 (b) dynamically configuring, in response to geometric constraints associated with a  
5 patient's anatomy and an equipment configuration, a plurality of signal channels connected to  
6 the transducer elements, so as to produce a plurality of groups of transducer elements; and

7 (c) separately driving the groups of transducer elements.

1 18. The method of claim 17, wherein step (a) comprises providing the plurality of  
2 ultrasound transducer elements arranged in a planar two-dimensional phased array.

1 19. The method of claim 17, wherein step (a) comprises providing the plurality of  
2 ultrasound transducer elements arranged in a non-planar two-dimensional phased array.

1 20. The method of claim 17, wherein the plurality of signals channels is configured so as to  
2 form first and second regions of grouped transducer elements, the first region capable of  
3 focusing at varying focal depths along a focal path in the direction of beam propagation and the  
4 second region capable of lateral beam steering in a direction perpendicular to beam  
5 propagation.

1 21. The method of claim 17, wherein the plurality of signals channels is configured so as to  
2 form first and second regions of grouped transducer elements, the first region capable of beam  
3 steering into a first selected volume and the second region capable of beam steering into a  
4 second selected volume.



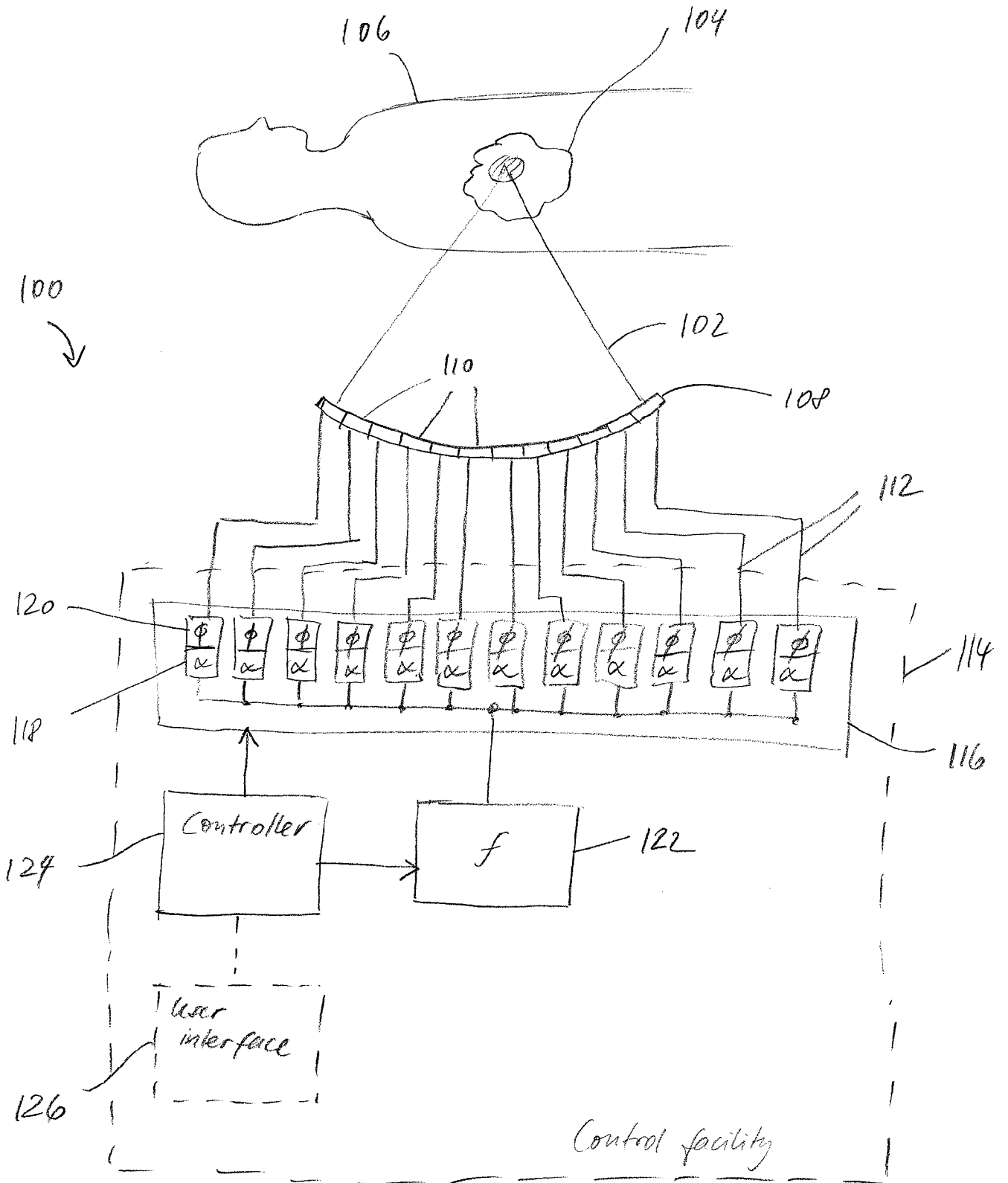


Fig. 1

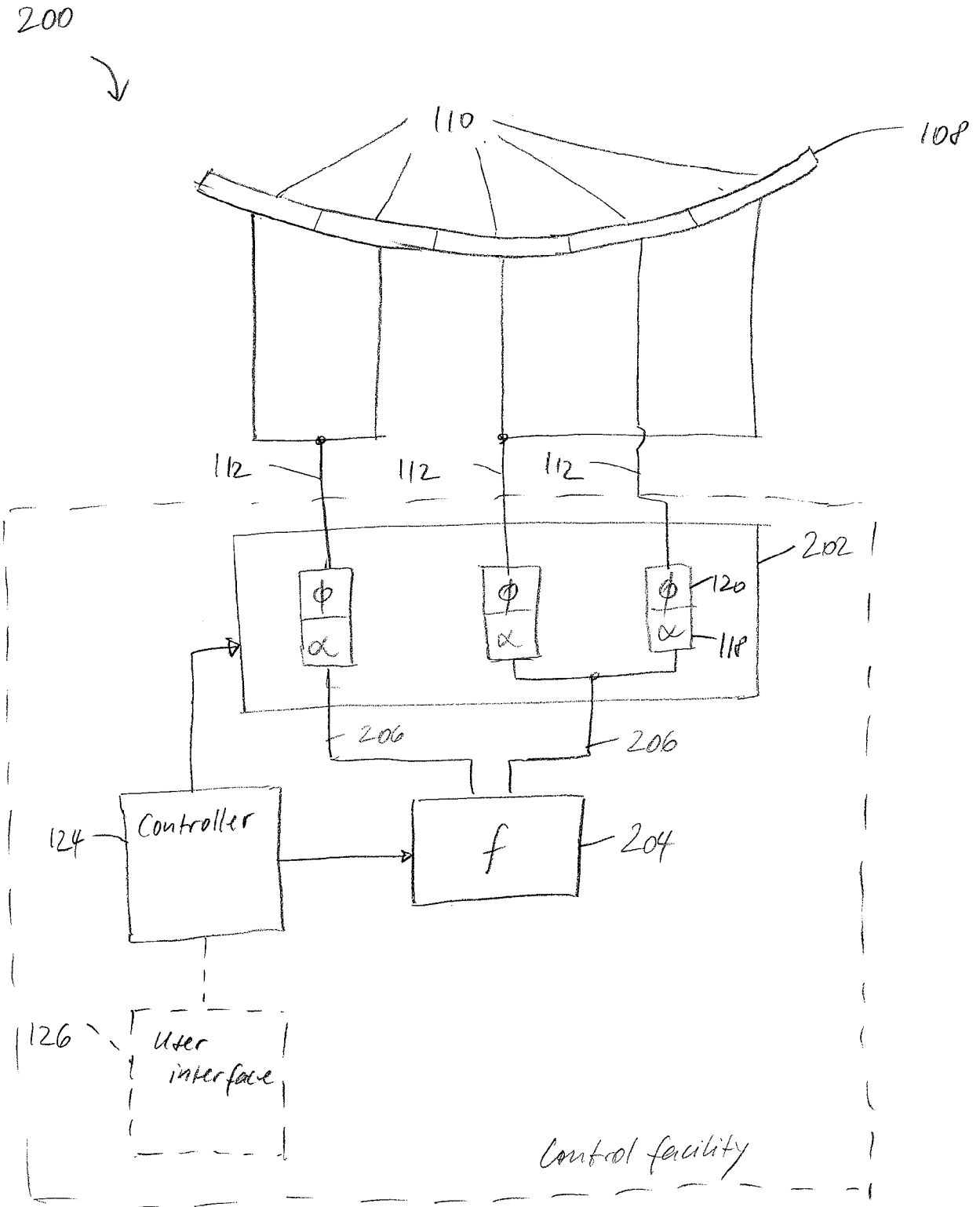


Fig. 2

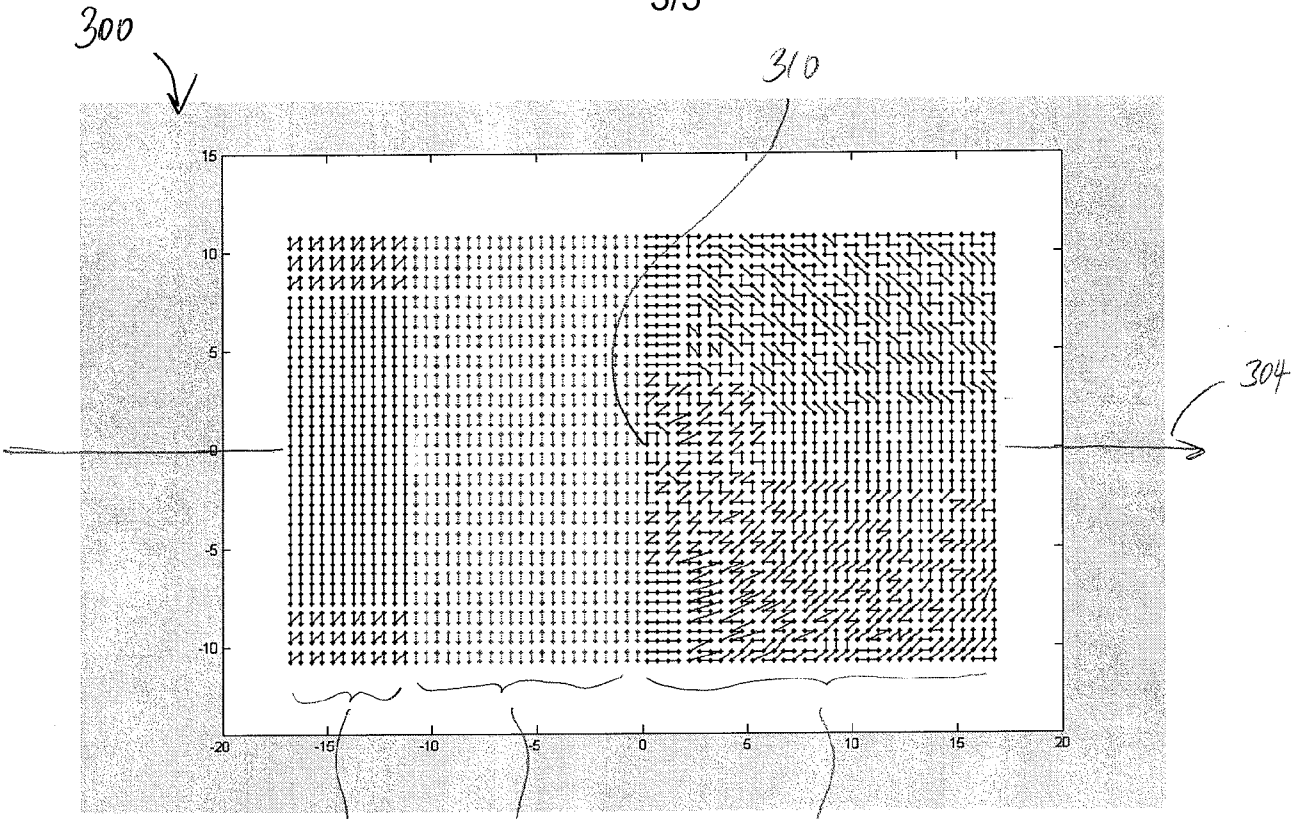


FIG. 2

302

306

30A

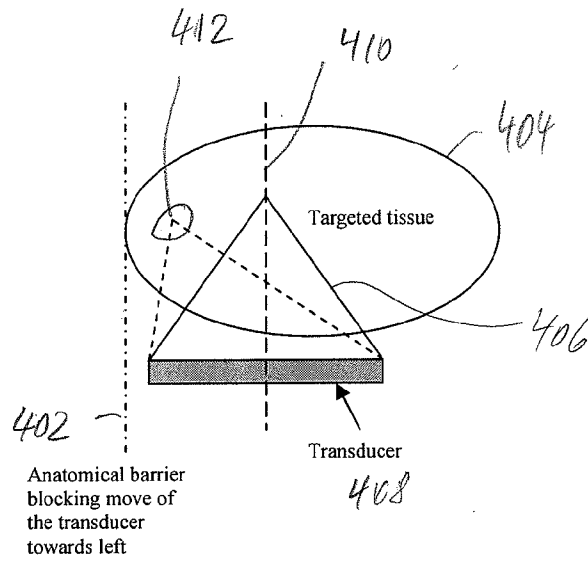


FIG. 4

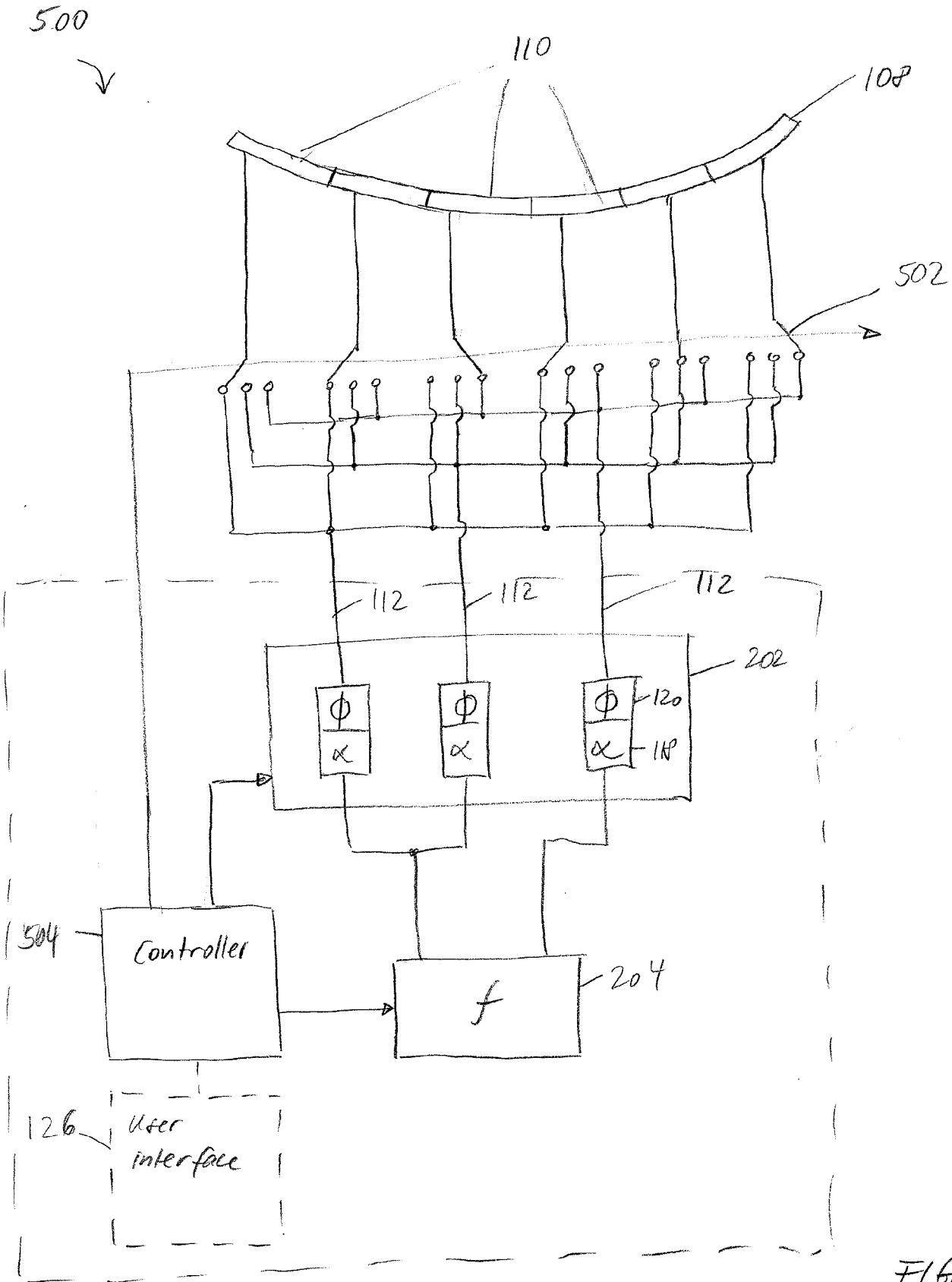


Fig. 5