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(54) **METHOD AND APPARATUS FOR ULTRASOUND SPATIAL COMPOUND IMAGING WITH ADJUSTABLE APERTURE CONTROLS**

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(57) **ABSTRACT**

A method and apparatus for ultrasound spatial compounding imaging with adjustable aperture controls is disclosed. The method and apparatus can improve the image quality of all frames by applying different aperture controls on each frame of the spatially compounded image. One or both of transmit and receive aperture controls may include preventing some element of the transducer array from transmitting or receiving, calculating weighting apodizations to combine with standard apodizations for each frame, or determining an aperture size based on an f-number for the transducer array for each frame.

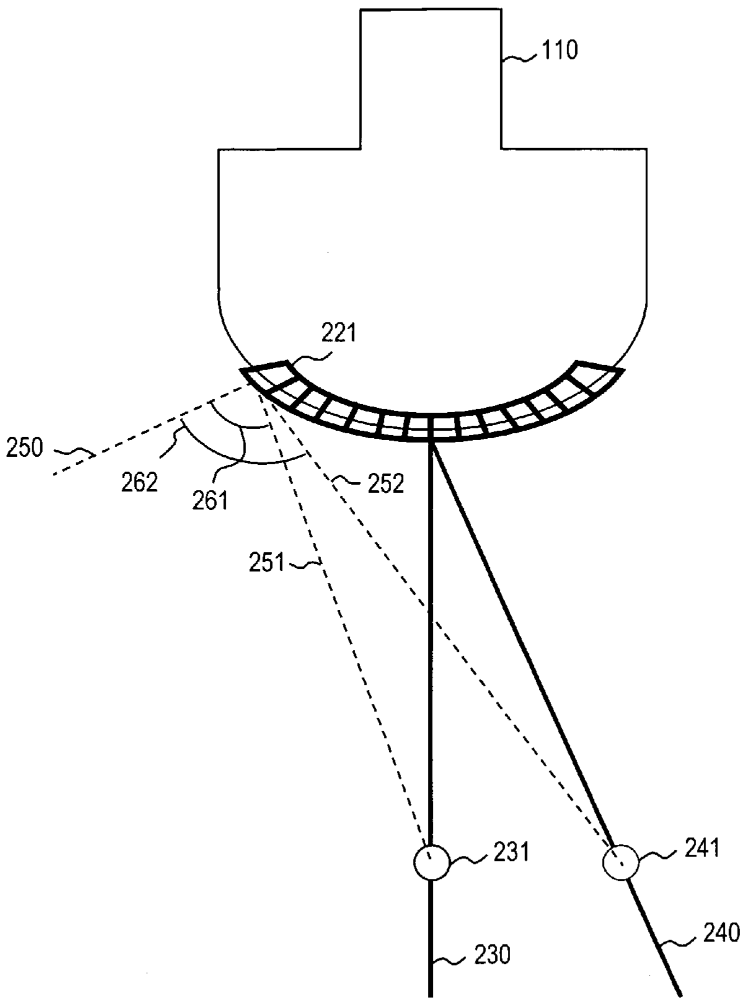


FIG. 1

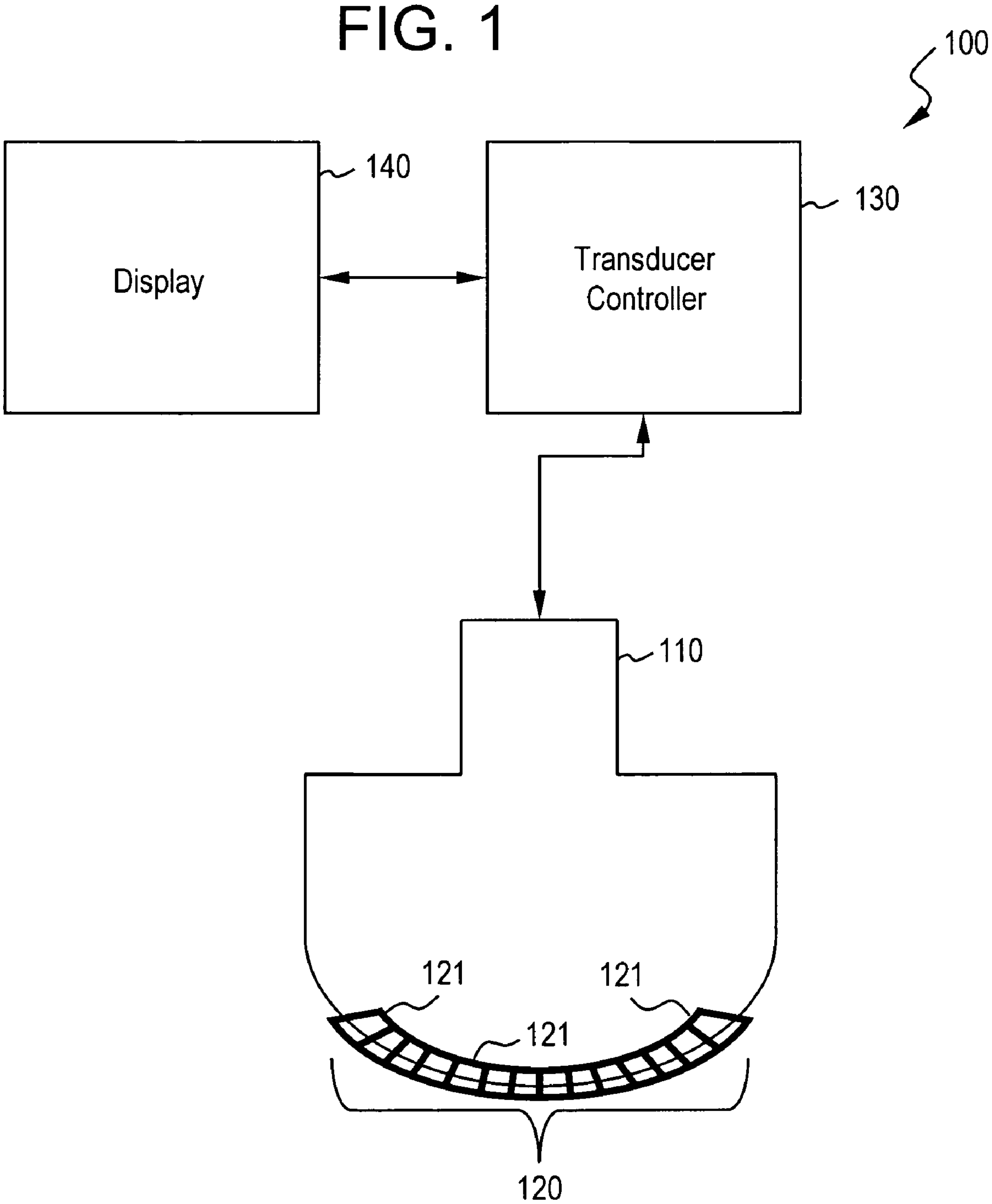

100
140
Display
130
Transducer Controller
110
121
121
121
120

FIG. 2

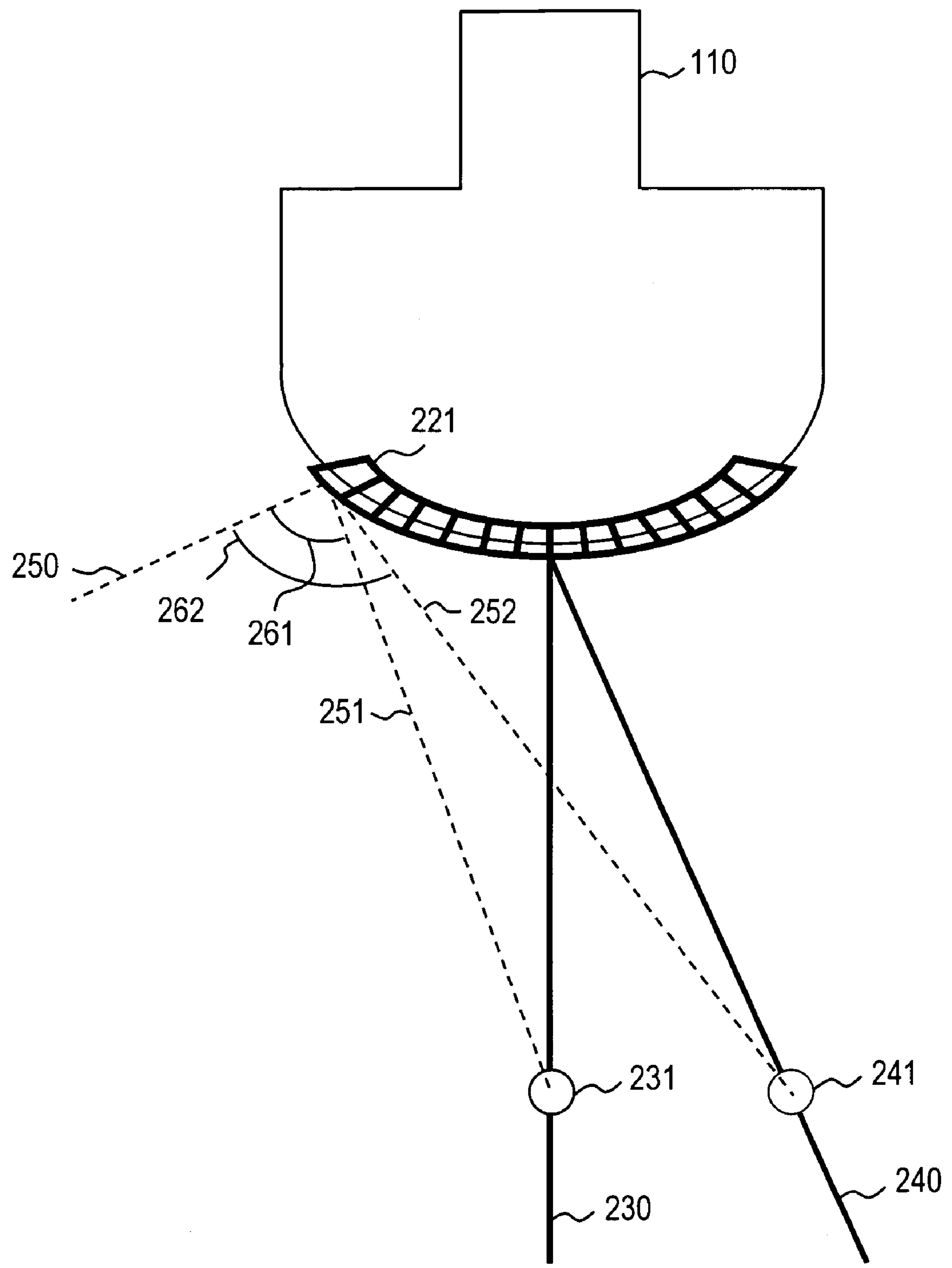


FIG. 3

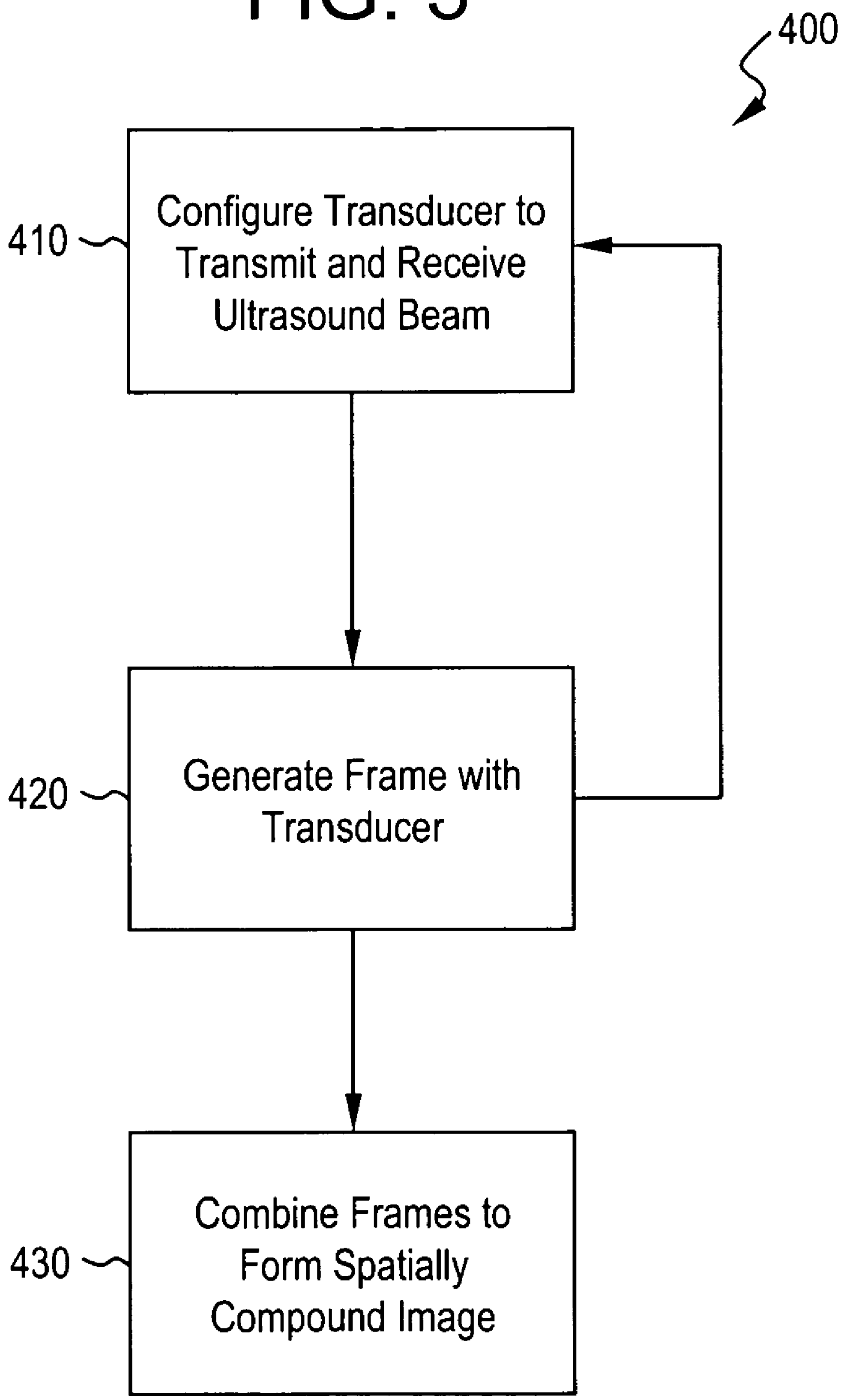

400
410
Configure Transducer to Transmit and Receive Ultrasound Beam
420
Generate Frame with Transducer
430
Combine Frames to Form Spatially Compound Image

FIG. 4

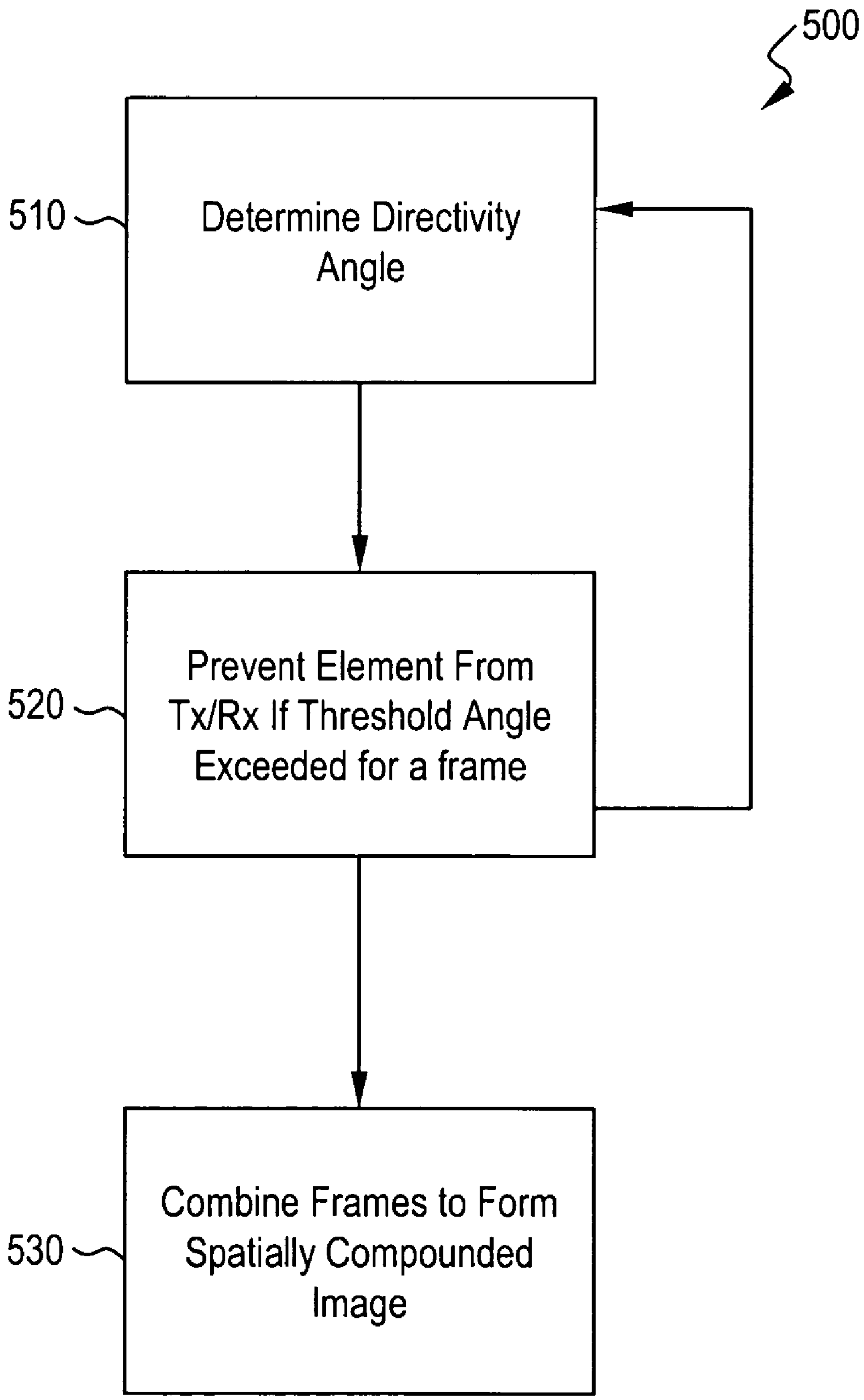

500
510
Determine Directivity Angle
520
Prevent Element From Tx/Rx If Threshold Angle Exceeded for a frame
530
Combine Frames to Form Spatially Compounded Image

FIG. 5

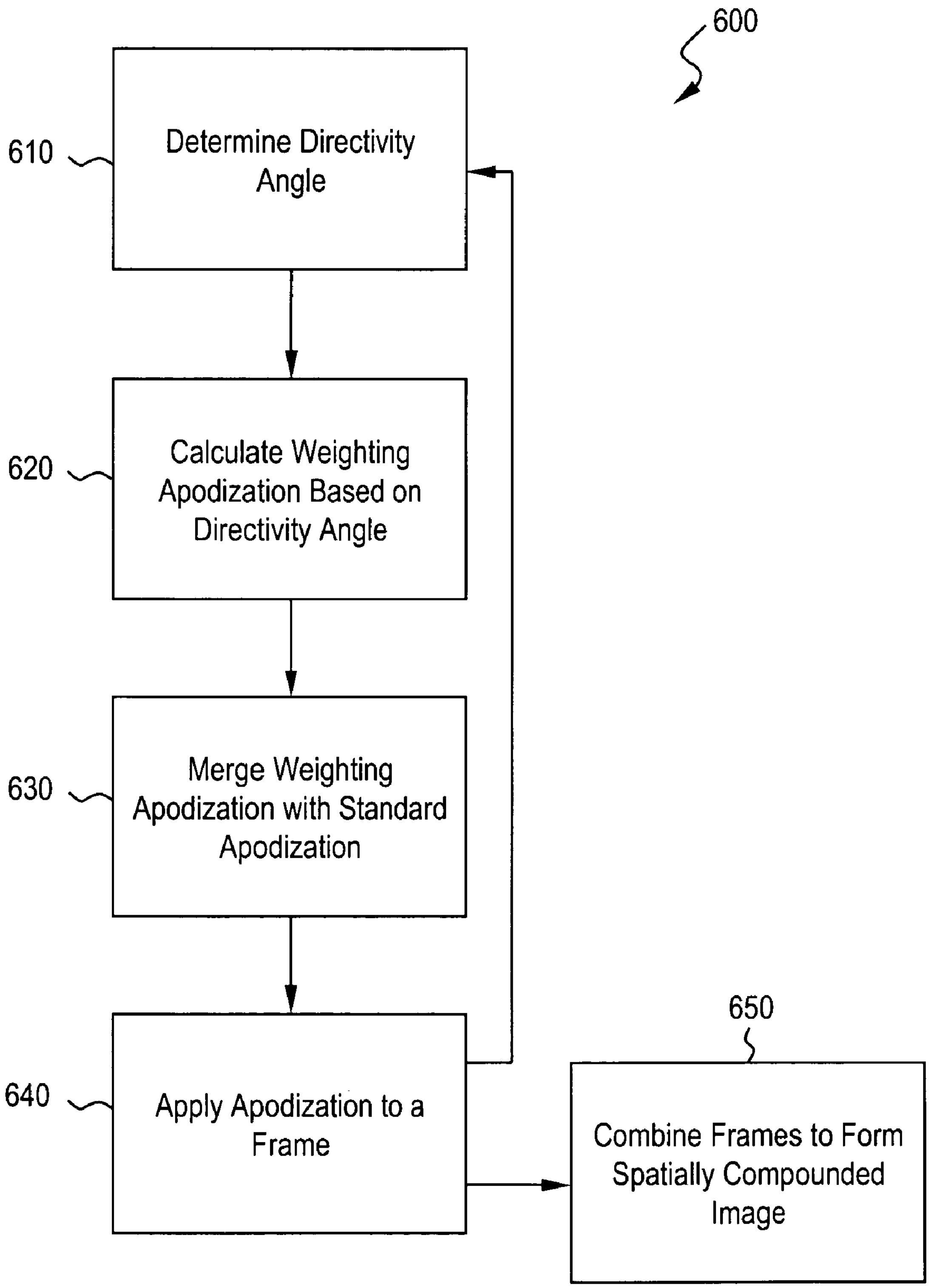

600
610
Determine Directivity Angle
620
Calculate Weighting Apodization Based on Directivity Angle
630
Merge Weighting Apodization with Standard Apodization
640
Apply Apodization to a Frame
650
Combine Frames to Form Spatially Compounded Image

FIG. 6

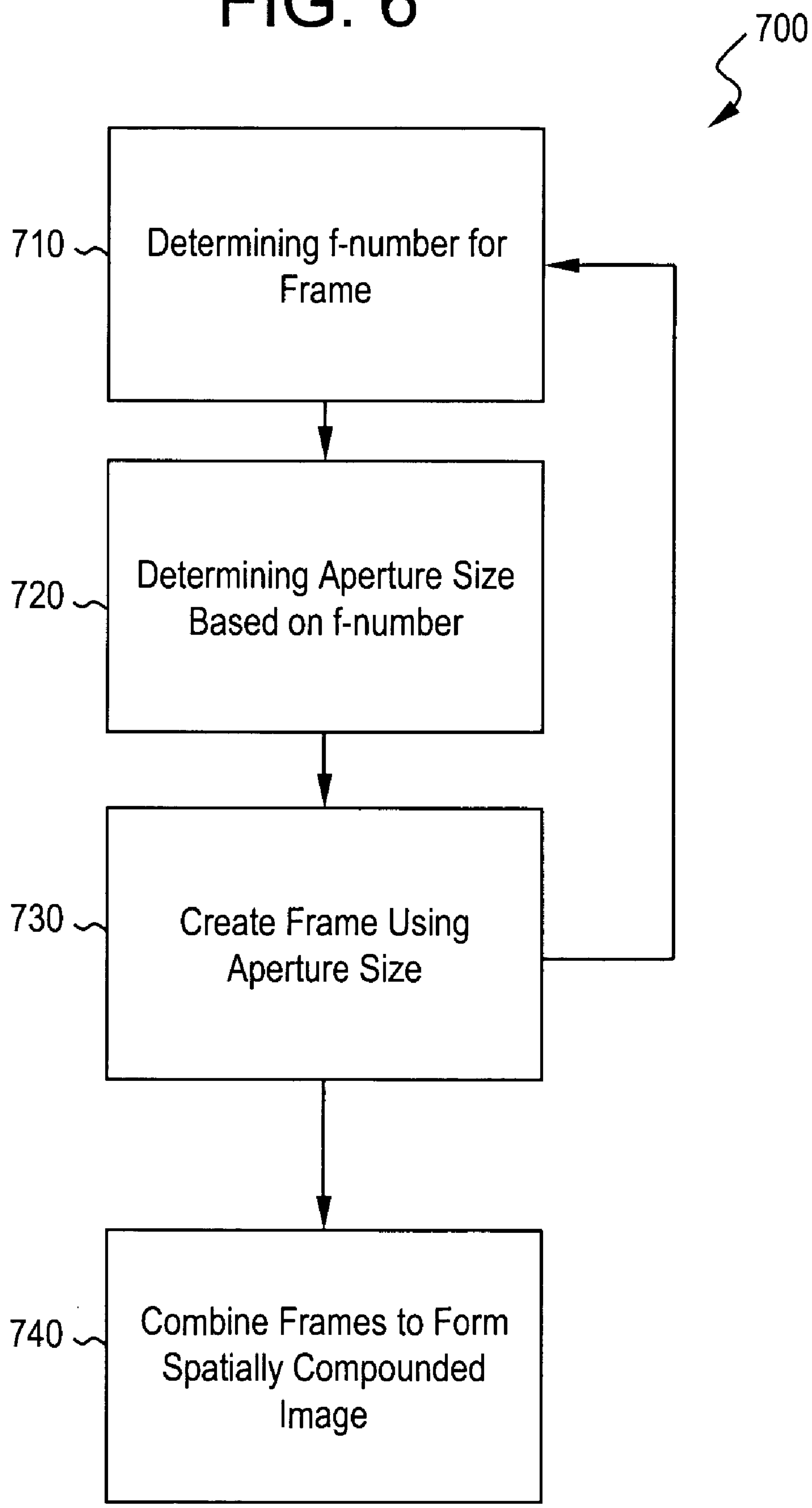
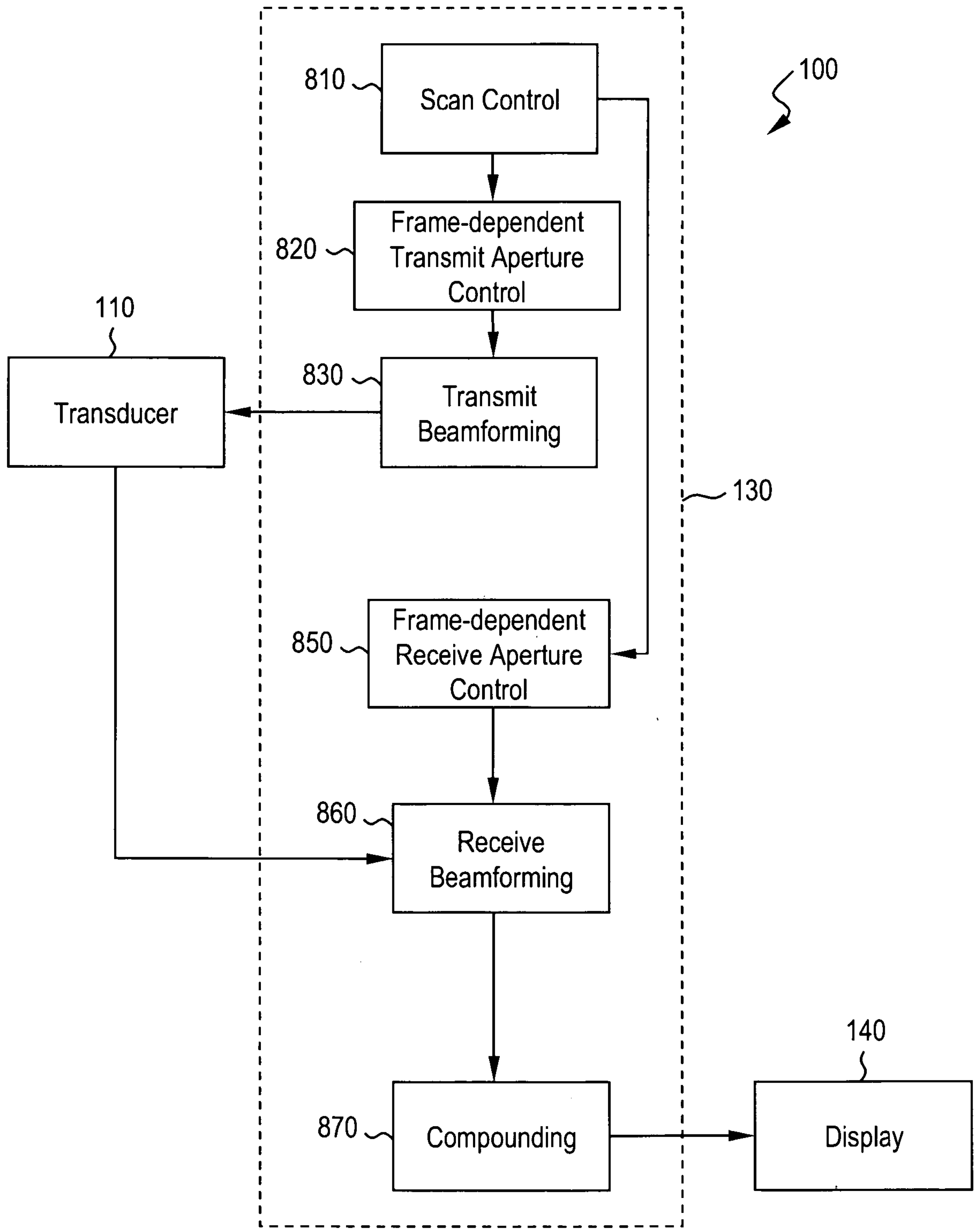

700
710
Determining f-number for Frame
720
Determining Aperture Size Based on f-number
730
Create Frame Using Aperture Size
740
Combine Frames to Form Spatially Compounded Image

FIG. 7



100
810
Scan Control
820
Frame-dependent Transmit Aperture Control
110
Transducer
830
Transmit Beamforming
130
850
Frame-dependent Receive Aperture Control
860
Receive Beamforming
140
870
Compounding
Display

FIG. 8

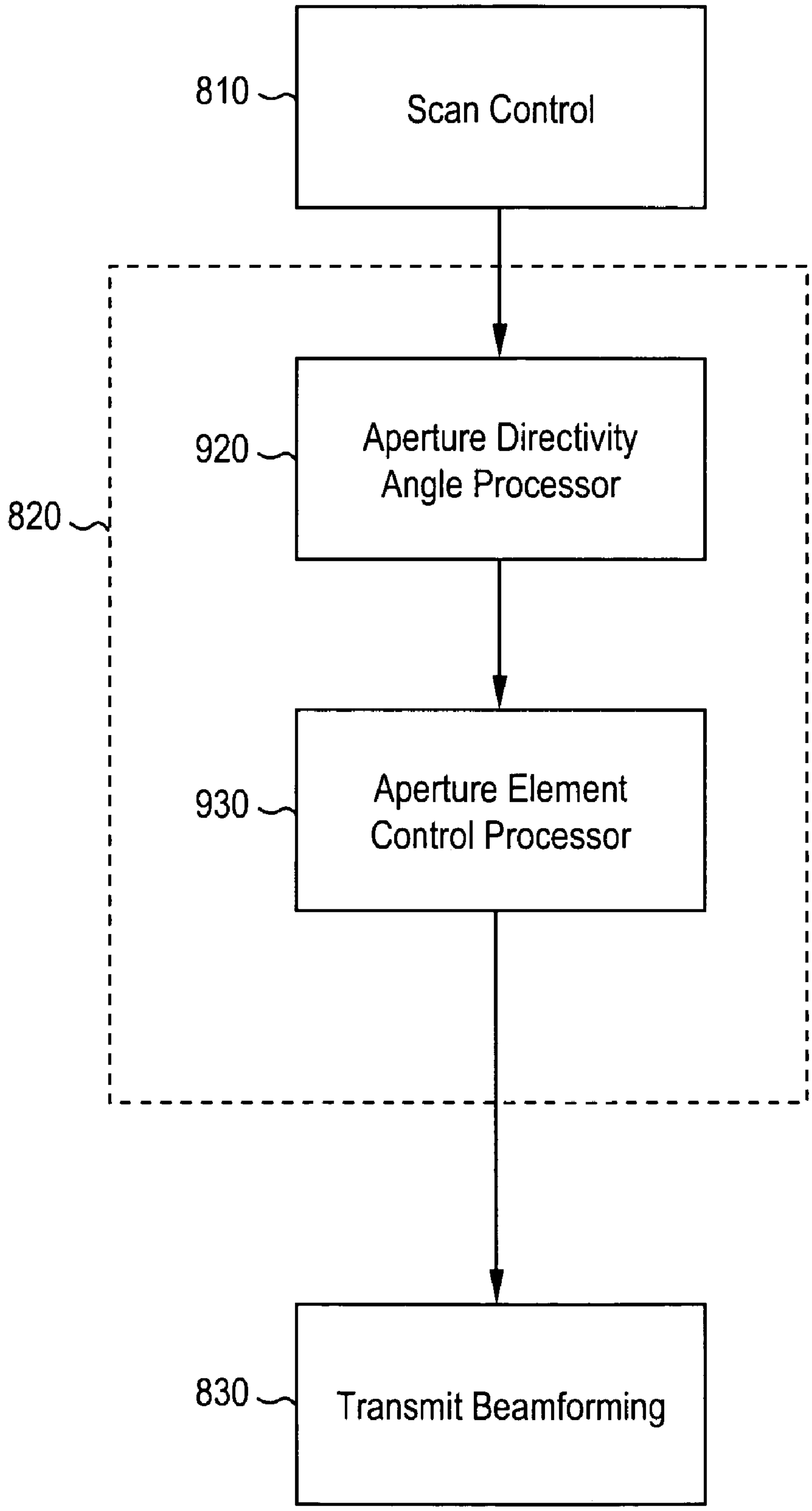

810
Scan Control
820
920
Aperture Directivity Angle Processor
930
Aperture Element Control Processor
830
Transmit Beamforming

FIG. 9

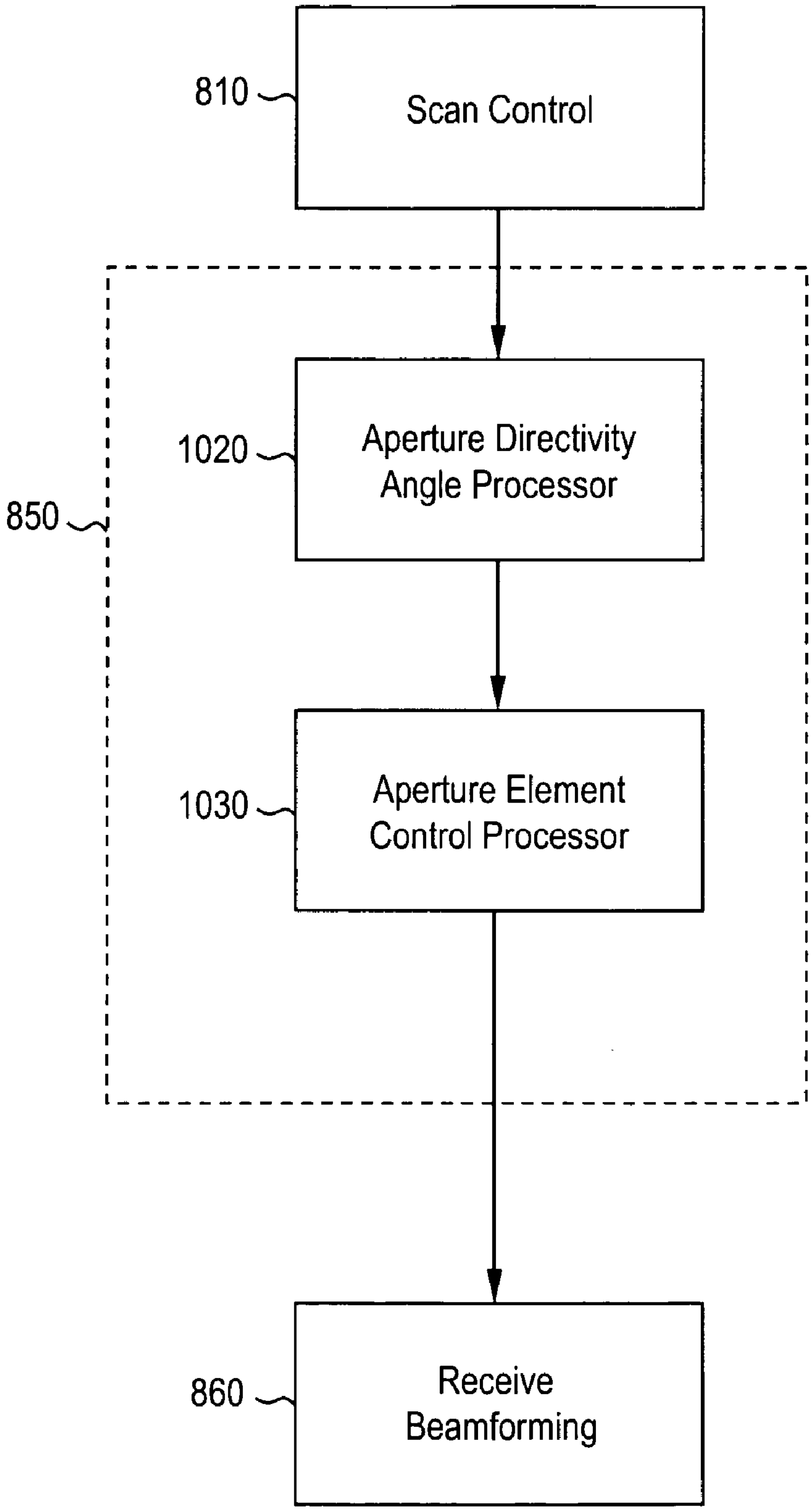
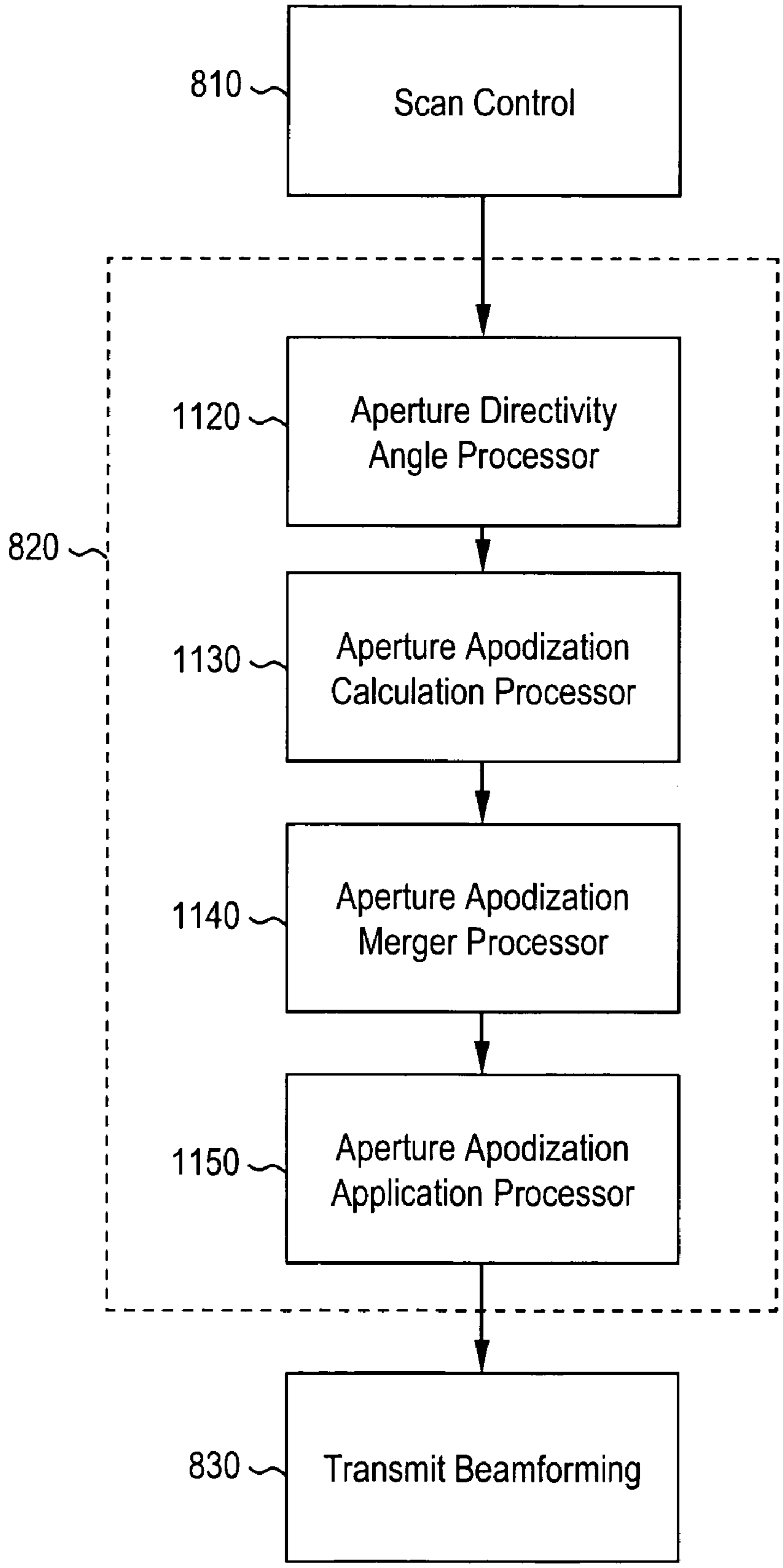

810
Scan Control
1020
Aperture Directivity Angle Processor
850
1030
Aperture Element Control Processor
860
Receive Beamforming

FIG. 10



810
Scan Control
820
1120
Aperture Directivity Angle Processor
1130
Aperture Apodization Calculation Processor
1140
Aperture Apodization Merger Processor
1150
Aperture Apodization Application Processor
830
Transmit Beamforming

FIG. 11

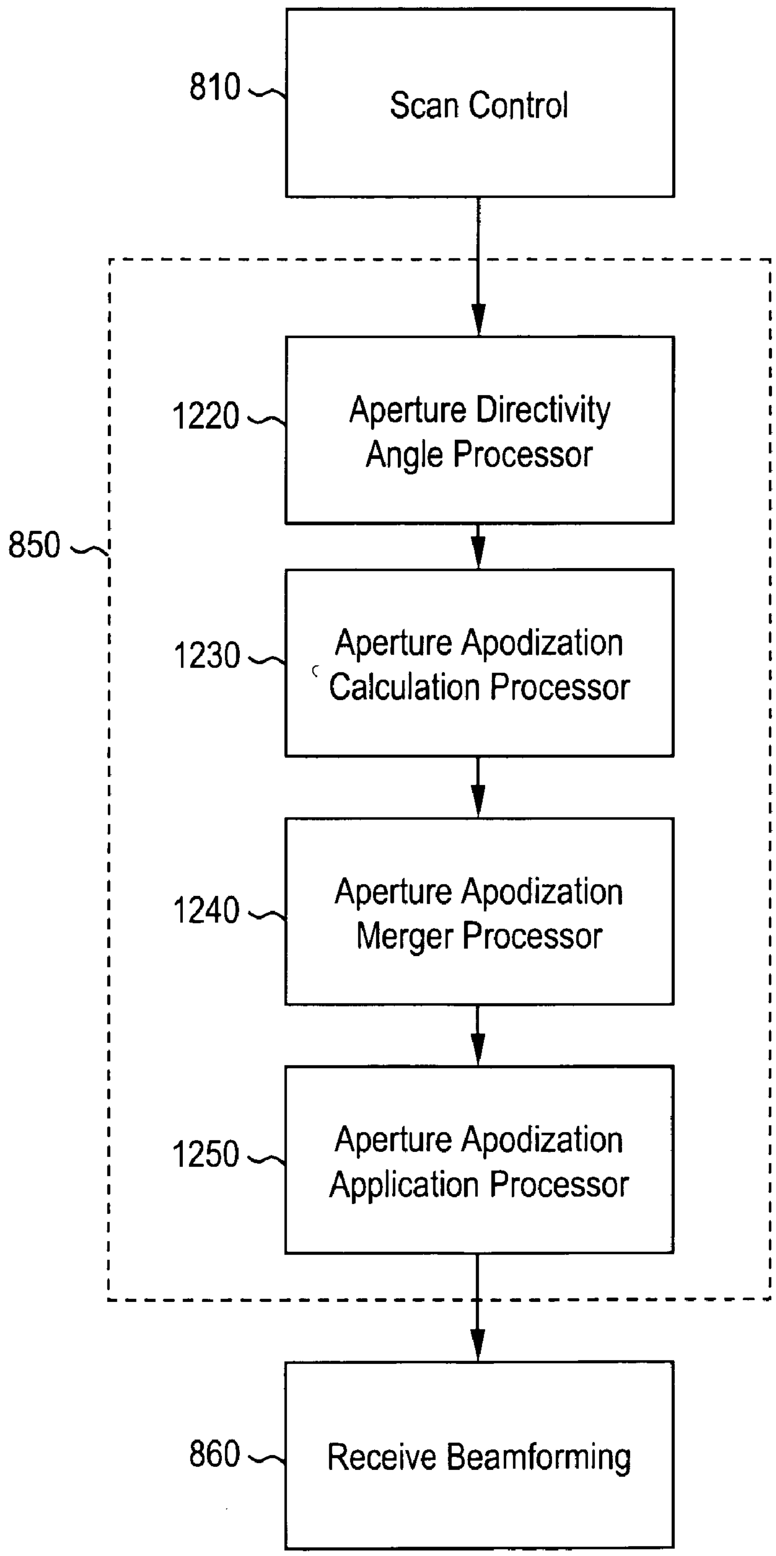

810
Scan Control
850
1220
Aperture Directivity Angle Processor
1230
Aperture Apodization Calculation Processor
1240
Aperture Apodization Merger Processor
1250
Aperture Apodization Application Processor
860
Receive Beamforming

FIG. 12

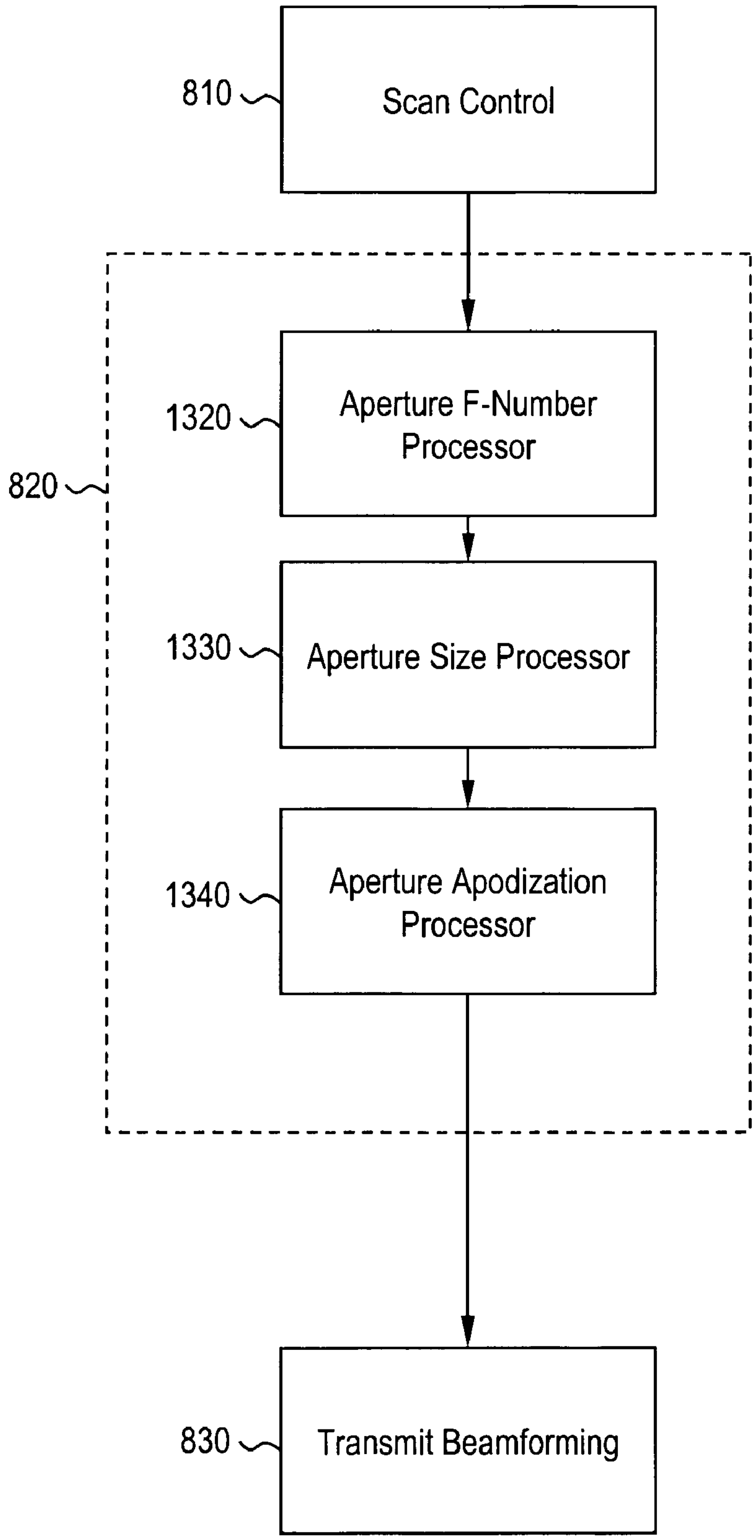
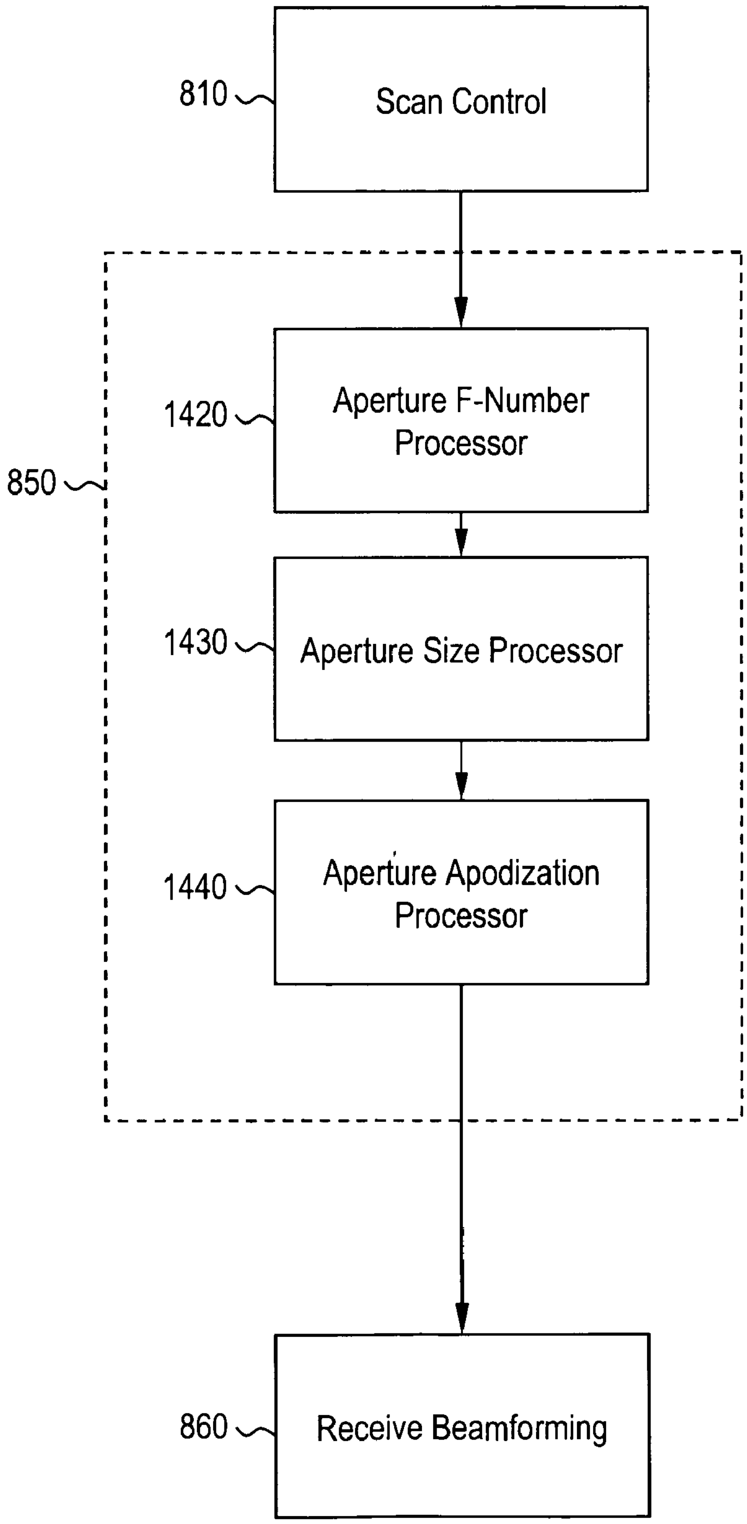

810
Scan Control
820
1320
Aperture F-Number Processor
1330
Aperture Size Processor
1340
Aperture Apodization Processor
830
Transmit Beamforming

FIG. 13


810
Scan Control
850
1420
Aperture F-Number Processor
1430
Aperture Size Processor
1440
Aperture Apodization Processor
860
Receive Beamforming

METHOD AND APPARATUS FOR ULTRASOUND SPATIAL COMPOUND IMAGING WITH ADJUSTABLE APERTURE CONTROLS

BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to ultrasound imaging. In particular, the present invention relates to a method and apparatus for ultrasound spatial compound imaging with adjustable aperture controls.

[0002] Spatial compounding is an advanced ultrasound imaging technique. In spatial compounding, ultrasound beams are transmitted and received in different directions. The directions may include a straight direction, as is typically performed in traditional ultrasound imagining, and steered directions that may be toward either side of the straight direction in the image plane. The image from each direction, i.e., frame, is incoherently summed together after registration to form a compounded image. The spatial compounding technique has several advantages, including: reducing speckles, enhancing boundaries, and improving contrast resolution.

[0003] However, one of the shortcomings of the technique is that the image quality of the steered frames is typically lower than the straight frame. Since steered frames are summed with the straight frame using essentially equal weighting, poor image quality in steered frames causes degradation in compounding image resolution.

[0004] The lower image quality of steered frames is partially because of the directivity of transducer elements. To characterize directivity, a directivity angle is defined. A directivity angle of an element is based at least in part on the angle between a direction perpendicular to the surface of an element and the propagation path of an ultrasound beam. A transducer element is capable of transmitting maximal acoustic pressure and receiving acoustic signal most efficiently in the direction that is perpendicular to the element's surface. This transmitting and receiving efficiency is reduced rapidly when the beam propagation path is steered. For a fixed aperture, elements at the edges may have significantly larger directivity angles for steered beams than for straight beams. Consequently, for a fixed aperture, the signal-to-noise ratio when the beam is steered is inferior to that when the beam is straight.

[0005] Grating lobe artifacts are another concern for steered frames. Grating lobes are cloud-like artifacts caused by element pitch not being smaller than half the wavelength. These artifacts are significantly worse when a beam is steered, that is, when elements have larger directivity angles.

[0006] In spatial compounding, typical practice is to apply the same transmitting and receiving apertures and apodizations on the straight frame and the steered frames. However, this is not optimal for contrast resolution. For example, an aperture setting that provides the best spatial resolution in the straight frame may result in excessive grating lobes and noise in some steered frames. On the other hand, an aperture setting that is optimal for grating lobe and noise suppression in a steered frame may result in poor spatial resolution in the straight frame.

[0007] Thus, a need exists for a method and apparatus for ultrasound spatial compounding imaging with adjustable aperture controls. Such a method and apparatus can improve the image quality of all frames by applying different aperture controls on each frame of the spatially compounded image.

BRIEF SUMMARY OF THE INVENTION

[0008] The present invention provides a method for ultrasound spatial compound imaging with adjustable aperture controls. The method includes determining two directivity angles for an element of an ultrasound transducer array, preventing the element from transmitting and/or receiving, and combining at least the two frames to form a spatially compounded image. The two directivity angles correspond to two frames of the spatially compounded image. The element is prevented from transmitting and/or receiving for a frame if the element's directivity angle for the frame exceeds a threshold angle.

[0009] The present invention also provides a method for ultrasound spatial compound imaging using weighting apodizations. The method includes determining two directivity angles for an element of an ultrasound transducer array, calculating two ultrasound signal weighting apodizations, merging each weighting apodization with a standard apodization to create a final apodization, applying each final apodization to ultrasound signals, and combining at least two frames to form a spatially compounded image. The two directivity angles correspond to two frames of the spatially compounded image. The weighting and final apodizations also correspond to two frames of the image.

[0010] The present invention also provides a method for ultrasound spatial compound imaging with adjustable aperture controls related to f-numbers. The method includes: determining two f-numbers for a transducer array, determining two aperture sizes for the transducer array, creating at least two frames, and combining at least those two frames to form a spatially compounded image. The two f-numbers correspond to two frames of the image. The two aperture sizes correspond to two frames of the image and are based at least in part on the two f-numbers. The two frames are created by using at least the two aperture sizes.

[0011] The present invention also provides an apparatus for ultrasound spatial compound imaging with adjustable aperture controls. The apparatus includes a transducer array, an aperture directivity angle processor, an aperture element control, and a compounding processor. The transducer array includes at least one element capable of transmitting and/or receiving an ultrasound beam for one or more frames in a spatially compounded image. The aperture directivity angle processor determines a directivity angle for at least one element of the array for each of at least two frames of the image. The aperture element control prevents the element from transmitting and/or receiving the ultrasound beam for a frame if the directivity angle for that element for that frame exceeds a threshold. The compounding processor combines at least two frames to form a spatially compounded image.

[0012] The present invention also provides an apparatus for ultrasound spatial compound imaging with adjustable aperture controls using weighted apodizations. The apparatus includes a transducer array, an aperture directivity angle processor, an aperture apodization calculation processor, an aperture apodization merger processor, an aperture apodization application processor, and a compounding processor. The transducer array includes at least one element capable of transmitting and/or receiving an ultrasound beam for one or more frames in a spatially compounded image. The aperture directivity angle processor determines a directivity angle for at least one element of the array for each of at least two frames of the image. The aperture apodization calculation processor calculates two ultrasound signal weighting apodizations, each based at least in part on the respective directivity angles. The aperture apodization merger processor merges each weighting apodization with a standard signal apodization to create a final apodization for each frame. The aperture apodization application processor applies the final apodizations to ultrasound signals transmitted and/or received during at least one of the frames. The compounding processor combines at least two frames to form a spatially compounded image.

[0013] The present invention also provides an apparatus for ultrasound spatial compound imaging with adjustable aperture controls related to f-numbers. The apparatus includes a transducer array, an aperture f-number processor, an aperture size processor, and a compounding processor. The transducer array includes at least one element capable of transmitting and/or receiving an ultrasound beam for one or more frames in a spatially compounded image. The aperture f-number processor determines at least two f-numbers for the array corresponding to at least two frames of the image. The aperture size processor determines aperture sizes for the transducer array for respective frames based at least in part on the corresponding f-numbers. The compounding processor combines at least two frames to form a spatially compounded image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] **FIG. 1** illustrates a logical component diagram of an ultrasound imaging system used in accordance with an embodiment of the present invention.

[0015] **FIG. 2** illustrates the transducer of the ultrasound imaging system used in accordance with an embodiment of the present invention.

[0016] **FIG. 4** illustrates a flow diagram for a method for ultrasound spatial compound imaging with adjustable aperture controls in accordance with an embodiment of the present invention.

[0017] **FIG. 5** illustrates a flow diagram for a method for ultrasound spatial compound imaging with adjustable aperture controls in accordance with an embodiment of the present invention.

[0018] **FIG. 6** illustrates a flow diagram for a method for ultrasound spatial compound imaging with adjustable aperture controls using weighting apodizations in accordance with an embodiment of the present invention.

[0019] **FIG. 7** illustrates a flow diagram for a method for ultrasound spatial compound imaging with adjustable aperture controls related to f-numbers in accordance with an embodiment of the present invention.

[0020] **FIG. 8** illustrates a logical component diagram of an ultrasound imaging system used in accordance with an embodiment of the present invention.

[0021] **FIG. 9** illustrates a logical component diagram of the frame-dependent transmit aperture control used in accordance with an embodiment of the present invention.

[0022] **FIG. 10** illustrates a logical component diagram of the frame-dependent receive aperture control used in accordance with an embodiment of the present invention.

[0023] **FIG. 11** illustrates a logical component diagram of the frame-dependent transmit aperture control used in accordance with another embodiment of the present invention.

[0024] **FIG. 12** illustrates a logical component diagram of the frame-dependent receive aperture control used in accordance with another embodiment of the present invention.

[0025] **FIG. 13** illustrates a logical component diagram of the frame-dependent transmit aperture control used in accordance with another embodiment of the present invention.

[0026] **FIG. 14** illustrates a logical component diagram of the frame-dependent receive aperture control used in accordance with another embodiment of the present invention.

[0027] The foregoing summary, as well as the following detailed description of certain embodiments of the present invention, will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, certain embodiments are shown in the drawings. It should be understood, however, that the present invention is not limited to the arrangements and instrumentality shown in the attached drawings.

DETAILED DESCRIPTION OF THE INVENTION

[0028] **FIG. 1** illustrates a logical component diagram of an ultrasound imaging system **100** used in accordance with an embodiment of the present invention. The ultrasound imaging system **100** includes an ultrasound transducer **110**, a transducer controller **130**, and a display **140**. The ultrasound transducer **110** includes an array **120** of transducer elements **121**.

[0029] The ultrasound transducer **110** is in communication with the transducer controller **130**. The transducer controller **130** is in communication with the display **140**. The ultrasound transducer **110** is in communication with one or more of the elements **121** in the array **120**.

[0030] The transducer controller **130** can include any processor capable of digital and/or analog communication with the transducer **110**. For example, the transducer controller **130** may include a microprocessor with embedded software. As another example, the transducer controller **130** may be implemented entirely in hardware, entirely in software running on a computer or microprocessor, or some combination of hardware and software.

[0031] The transducer controller **130** may also include a computer with an input device for users of the system **100** to input imaging specifications or other information. Input imaging specifications may include one or more of a steering angle of an ultrasound beam, a focal distance or point, a frequency, a threshold angle, or an f-number, for example. For example, a user could input a steering angle of 10 degrees, a focal distance of 10 cm, a frequency of 3 MHz, a threshold angle of 30 degrees, and an f-number of 2.In addition, the transducer controller **130** may be capable of image processing.

[0032] In operation, ultrasound imaging specifications are communicated between the transducer controller **130** and the ultrasound transducer **110**. The ultrasound imaging specifications can be communicated over a digital or analog signal, for example. The ultrasound imaging specifications may include one or more of a steering angle of a transmitted ultrasound beam, a focal distance, a transmit waveform, a frequency, a transmit indicator, and a receive indicator for one or more elements **121** of the array **120**. A transmit indicator may include a direction to one or more elements **121** to transmit an ultrasound waveform, for example. Similarly, a receive indicator may include a direction to one or more elements **121** to receive an ultrasound waveform, for example.

[0033] In addition, an ultrasound transmission aperture size may be communicated from the transducer controller **130** to the transducer **110**. Similarly, an ultrasound receive aperture size may be communicated from the transducer controller **130** to the transducer **110**. The transmission and receive aperture sizes represent which elements **121** of the array **120** are to be utilized in transmitting and receiving an ultrasound beam, respectively. For example, a first aperture size may include 80% of all elements **121** of the array **120** while a second aperture size may include 60% of all elements **121** of the array **120**.

[0034] Received ultrasound signals may be communicated between the transducer **110** and the transducer controller **130**. Received ultrasound signals may be based on at least a strength of one or more ultrasound beams received at or measured by one or more elements **121** in the array **120**.

[0035] The transducer controller **130** may also be in communication with the display **140**. The received ultrasound signals from one or more of the elements **121** of the transducer array **120** can be employed by the transducer controller **130** to produce a frame of a spatially compounded image. The transducer controller **130** forms a spatially compounded image by combining two or more frames. One or more individual frames and/or a spatially compounded image may be communicated from the transducer controller **130** to the display **140**.

[0036] In another embodiment of the present invention, the transducer controller **130** may be in communication with or include a data storage medium (not shown), such as a hard disk drive, tape drive, or optical drive. In this configuration, one or more individual frames and/or spatially compounded image information may be stored by the data storage medium for later display or processing.

[0037] In another embodiment of the present invention, the transducer controller **130** may be in communication with or include a network interface controller (not shown) for communication on a network, such as an Ethernet, Asynchronous Transfer Mode (ATM), or other electrical, optical, or wireless networking medium. In such an embodiment, one or more individual frames and/or spatially compounded image information may be transmitted to another device on the network for storage, processing, display, or other use.

[0038] **FIG. 2** illustrates the transducer **110** of the ultrasound imaging system **100** used in accordance with an embodiment of the present invention. In particular, a first element **221** is illustrated to demonstrate certain concepts. Element **221** is similar to any element **121** of the array of transducer elements **120** of the transducer **110**.

[0039] In operation, the transducer **110** directs one or more of the elements **121** of the array **120** to transmit and/or receive one or more ultrasound beams. An ultrasound beam may be, for example, a straight beam **230** or a steered beam **240**. A straight beam **230** can be an ultrasound beam transmitted in a direction generally along the major axis of the transducer **110**. A steered beam **240** can be an ultrasound beam transmitted in a direction other than that of a straight beam **230**. For example, a steered beam **240** may have a propagation path that is 10 degrees from the propagation path of a straight beam **230**.

[0040] One or more elements **121** transmit one or more ultrasound beams towards a focus point. A straight beam **230** from element **221** may have a different focus point **231** than a focus point **241** for a steered beam **240**, for example. Generally, a focus point **231, 241** is located at a point of interest in an ultrasound image.

[0041] A directivity angle of an element **221** can be based on at least the angle between a direction perpendicular to a transmitting or receiving surface of an element **221** and the propagation path of an ultrasound beam either transmitted or received by element **221**. For example, a propagation path can include a path between the element **221** and a focal point of an ultrasound beam. For example, for a straight ultrasound beam **230** with focal point **231**, the directivity angle **261** includes the angle between the direction **250** (representing a direction perpendicular to the element **221**) and the path **251** between the element **221** and the focal point **231**. In another example, for a steered ultrasound beam **240** with focal point **241**, the directivity angle **262** includes the angle between the direction **250** and the path **252** between the element **221** and the focal point **241**. The directivity angles for a single element **221** in two frames of a spatially compounded image may differ.

[0042] **FIG. 8** illustrates a logical component diagram of an ultrasound imaging system **100** used in accordance with an embodiment of the present invention. The transducer controller **130**, as exemplified in **FIG. 8**, includes a scan control **810**, a frame-dependent transmit aperture control **820**, a transmit beamforming processor **830**, a frame-dependent receive aperture control **850**, a receive beamforming processor **860**, and a compounding processor **870**.

[0043] The scan control **810** is in communication with the frame-dependent transmit aperture control **820** and the frame-dependent receive aperture control **850**. The frame-dependent transmit aperture control **820** is in communication with the transmit beamforming processor **830**. The transmit beamforming processor **830** is in communication with the transducer **110**. The transducer **110** is in communication with the receive beamforming processor **860**. The frame-dependent receive aperture control **850** is also in communication with the receive beamforming processor **860**. The receive beamforming processor **860** is in communication with the compounding processor **870**. The compounding processor **870** can be in communication with the display **140**.

[0044] In operation, with additional reference to **FIG. 2**, the scan control **810** determines the directivity of one or more ultrasound beams for one or more frames of a spatially compounded image. The ultrasound beam may be, for example, a straight beam **230** or a steered beam **240**. The scan control **810** may communicate ultrasound beam information to at least one of the frame-dependent transmit and receive aperture controls **820, 850**. The ultrasound beam information may include, for example, the elements **121** of the transducer array **120** to be used and/or the steering angle of an ultrasound beam.

[0045] The frame-dependent transmit and receive aperture controls **820, 850** can perform various operations under one or more embodiments of the present invention, as discussed below. In general, the frame-dependent transmit and receive aperture controls **820, 850** can include of one or more processors. The aperture controls **820, 850** may provide for a different transducer **110** aperture size and/or apodization (as described below) for one or more ultrasound beams transmitted and/or received by the transducer **110**. These processors may be implemented in software or hardware, and may exist as separate applications and/or devices may be integrated into one or more applications and/or devices.

[0046] The transmit beamforming processor **830** generates signals that are communicated to one or more of the elements **121** in the array **120**. The signals may include, for example, a transmit aperture size of the transducer **110** and/or an ultrasound beam directivity angle for one or more of the elements **121**. Based on at least these signals, the transducer **110** transmits ultrasound beams, as described above.

[0047] As described above, the transducer **110** can also receive ultrasound beams. Once the transducer **110** has received one or more ultrasound beams, the transducer **110** communicates one or more image signals to the receive beamforming processor **860**. The image signals can include, for example, data based on at least one or more received ultrasound beams. The receive beamforming processor **860** can combine a plurality of the image signals to form a beam, for example.

[0048] After receiving image signals, the receive beamforming processor **860** combines a plurality of the signals to form a beam. Typically, for example, a hundred or more parallel beams may be formed. The beamforming processor **860** then communicates the beams to compounding processor **870**.

[0049] The compounding processor **870** generates the spatially compounded image based on at least the beams communicated to it by the receive beamforming processor **860**. The spatially compounded image may then be communicated to the display **140**. The display **140** can visually display the spatially compounded image to the user.

[0050] **FIG. 9** illustrates a logical component diagram of the frame-dependent transmit aperture control **820** used in accordance with an embodiment of the present invention. The frame-dependent transmit aperture control **820** can include an aperture directivity angle processor **920** and an aperture element control processor **930**.

[0051] The scan control **810** is in communication with the aperture directivity angle processor **920**. The aperture directivity angle processor **920** is in communication with the aperture element control processor **930**. The aperture element control processor **930** is in communication with the transmit beamforming processor **830**.

[0052] In operation, the aperture directivity angle processor **920** calculates a directivity angle of an element, such as element **221**, for a frame of a spatially compounded image. The directivity angle can be based on at least the ultrasound beam information communicated from the scan control **810**, as described above. The directivity angle is communicated to the aperture element control processor **930**.

[0053] The aperture control processor **930** receives the directivity angle and compares the angle to one or more threshold angles. If the aperture element control processor **930** determines that the directivity angle exceeds a threshold angle, then the element, such as **221**, may be prevented from transmitting for that frame. The aperture element control processor **930** may prevent the element from transmitting by, for example, directing the transducer **110** to power down the element or to prevent the element **221** from transmitting an ultrasound beam.

[0054] The threshold angle may be specified in a variety of ways, for example, by a user input or a software protocol. In addition, the threshold angle may be determined automatically based on at least the usage of the ultrasound transducer **110**. For example, the threshold angle may be determined based on at least the frequency of the ultrasound beam and/or the focal depth. A threshold angle may be, for example, 0.5 radians or 30 degrees.

[0055] **FIG. 10** illustrates a logical component diagram of the frame-dependent receive aperture control **850** used in accordance with an embodiment of the present invention. The frame-dependent receive aperture control **850** may include an aperture directivity angle processor **1020** and an aperture element control processor **1030**.

[0056] The scan control **810** is in communication with the aperture directivity angle processor **1020**. The aperture directivity angle processor **1020** is in communication with the aperture element control processor **1030**. The aperture element control processor **1030** is in communication with the receive beamforming processor **860**.

[0057] In operation, the aperture directivity angle processor **1020** calculates a receive directivity angle of an element, such as element **221**, for a frame of a spatially compounded image. The receive directivity angle is communicated to the aperture element control processor **1030**.

[0058] The aperture element control processor **1030** then compares the receive directivity angle to one or more threshold angles. If the aperture element control processor **1030** determines that the receive directivity angle exceeds a threshold angle, then the element, such as **221**, may be prevented from receiving for that frame. The aperture element control processor **1030** may prevent the element from receiving by, for example, powering down the element or by ignoring data provided by the element.

[0059] **FIG. 11** illustrates a logical component diagram of the frame-dependent transmit aperture control **820** used in accordance with another embodiment of the present invention. The frame-dependent transmit aperture control **820** may include an aperture directivity processor **1120**, an aperture apodization calculation processor **1130**, an aperture apodization merger processor **1140**, and an aperture apodization application processor **1150**.

[0060] The scan control **810** is in communication with the aperture directivity angle processor **1120**. The aperture directivity processor **1120** is in communication with the aperture apodization calculation processor **1130**. The aperture apodization calculation processor **1130** is in communication with the apodization merger processor **1140**. The aperture apodization merger processor **1140** is in communication with the aperture apodization application processor **1150**. The aperture apodization application processor **1150** is in communication with the transmit beamforming processor **830**.

[0061] In operation, the aperture directivity processor **1120** calculates a directivity angle of an element, such as element **221**, for a frame of a spatially compounded image. The directivity angle is communicated to the aperture apodization calculation processor **1130**.

[0062] The aperture apodization calculation processor **1130** calculates a weighting apodization for the transmitted ultrasound signal. The weighting apodization can be based on at least the directivity angle communicated from the aperture directivity processor **1120**. The aperture apodization calculation processor **1130** communicates the weighting apodization to the aperture apodization merger processor **1140**.

[0063] The aperture apodization merger processor **1140** can combine the weighting apodization received from the aperture apodization calculation processor **1130** with a standard apodization to create a final apodization. The standard apodization can include an apodization window typically used in transmit and receive apertures. Standard apodizations can have different graphical shapes, such as Gaussian, flat, or Hamming. The final apodization may also be a combination or merger of a Gaussian apodization and an apodization based on an acceptance angle, for example. The final apodization may be asymmetric. The aperture apodization merger processor **1140** communicates the final apodization to the aperture apodization application processor **1150**.

[0064] The aperture apodization application processor **1150** applies the final apodization to the transmitted ultrasound signal, which is communicated to the transmit beamforming **830**. Before an apodization is applied, each element in an aperture can be applied with a waveform with the same amplitude. After an apodization is applied, the waveform amplitudes can be different for elements in the aperture. Typically, the amplitude and/or weighting are largest at the center of the aperture and smallest at the aperture edges.

[0065] **FIG. 12** illustrates a logical component diagram of the frame-dependent receive aperture control **850** used in accordance with another embodiment of the present invention. The frame-dependent receive aperture control **850** may include an aperture directivity processor **1220**, an aperture apodization calculation processor **1230**, an aperture apodization merger processor **1240**, and an aperture apodization application processor **1250**.

[0066] The scan control **810** is in communication with the aperture directivity angle processor **1220**. The aperture directivity processor **1220** is in communication with the aperture apodization calculation processor **1230**. The aperture apodization calculation processor **1230** is in communication with the apodization merger processor **1240**. The aperture apodization merger processor **1240** is in communication with the aperture apodization application processor **1250**. The aperture apodization application processor **1250** is in communication with the receive beamforming processor **860**.

[0067] In operation, the aperture directivity processor **1220** calculates a receive directivity angle of an element, such as element **221**, for a frame of a spatially compounded image. The receive directivity angle is communicated to the aperture apodization calculation processor **1230**.

[0068] The aperture apodization calculation processor **1230** calculates a weighting apodization for the received ultrasound signal. The weighting apodization can be based, at least in part, on the directivity angle communicated from the aperture directivity processor **1220**. The aperture apodization calculation processor **1230** communicates the weighting apodization to the aperture apodization merger processor **1240**.

[0069] The aperture apodization merger processor **1240** merges the weighting apodization received from the aperture apodization calculation processor **1230** with a standard apodization to create a final apodization, similar to as described above. The standard apodization may be a Gaussian apodization. The final apodization may be asymmetric. The aperture apodization merger processor **1240** communicates the final apodization to the aperture apodization application processor **1250**.

[0070] The aperture apodization application processor **1250** applies the final apodization to the received ultrasound signal, similar to as described above. A frame of a spatially compounded image is based on at least the application of the final apodization to the received ultrasound signal. The frame is then communicated to the receive beamforming processor **860**.

[0071] **FIG. 13** illustrates a logical component diagram of the frame-dependent transmit aperture control **820** used in accordance with another embodiment of the present invention. The frame-dependent transmit aperture control **820** may include an aperture f-number processor **1320** and an aperture size processor **1330**. An aperture apodization processor **1340** may also be present.

[0072] The scan control **810** is in communication with the aperture f-number processor **1320**. The aperture f-number processor **1320** is in communication with the aperture size processor **1330**. The aperture size processor **1330** may be in communication with the aperture apodization processor **1340**. The aperture size processor **1330** may be in communication with the transmit beamforming processor **830**. The aperture apodization processor **1340** may be in communication with the transmit beamforming processor **830**.

[0073] In operation, the aperture f-number processor **1320** determines an f-number for the array **120** of the ultrasound transducer **110** for a frame of a spatially compounded image. The f-number can include a ratio of focal depth to aperture size. The f-number may be based on at least a threshold acceptance angle and a steering angle for an ultrasound beam for the frame. The aperture f-number processor **1320** communicates the f-number to the aperture size processor **1330**.

[0074] The aperture size processor **1330** determines the aperture size of the array **120** of the ultrasound transducer based on at least the f-number. The aperture size relates to the number of elements **121** of the array **120** that are used to transmit an ultrasound beam. The aperture size processor **1330** may prevent an element from transmitting by communicating transmit indicators to the element based on whether the element is within the aperture size. The aperture size may be based on at least a focal depth for an ultrasound beam.

[0075] The aperture apodization processor **1340** applies a standard apodization to a transmitted ultrasound signal. The standard apodization may be, for example, a Gaussian apodization or a simple flat apodization. Based on at least the apodization, the transmit waveform with a proper amplitude can be applied to each element in the aperture.

[0076] **FIG. 14** illustrates a logical component diagram of the frame-dependent receive aperture control **850** used in accordance with another embodiment of the present invention. The frame-dependent receive aperture control **850** may include an aperture f-number processor **1420** and an aperture size processor **1430**. An aperture apodization processor **1440** may also be present.

[0077] The scan control **810** is in communication with the aperture f-number processor **1420**. The aperture f-number processor **1420** is in communication with the aperture size processor **1430**. The aperture size processor **1430** may be in communication with the aperture apodization processor **1440**. The aperture size processor **1430** may be in communication with the receive beamforming processor **860**. The aperture apodization processor **1440** may be in communication with the receive beamforming processor **860**.

[0078] In operation, the aperture f-number processor **1420** determines an f-number for the array **120** of the ultrasound transducer **110** for a frame of a spatially compounded image. The aperture f-number processor communicates **1420** the f-number to the aperture size processor **1430**.

[0079] The aperture size processor **1430** determines the aperture size of the array **120** of the ultrasound transducer based on at least the f-number. The aperture size relates to the number of elements **121** of the array **120** that are used to receive an ultrasound beam. The aperture size processor **1430** may prevent an element from receiving by communicating receive indicators to the element based on whether the element is within the aperture size. The aperture size may be based on at least a focal depth for an ultrasound beam.

[0080] The aperture apodization processor **1340** applies a standard apodization to a transmitted ultrasound signal. The standard apodization may be, for example, a Gaussian apodization or a simple flat apodization. Based on the apodization, the transmit waveform with a proper amplitude is applied to each element in the aperture.

[0081] **FIG. 4** illustrates a flow diagram for a method **400** for ultrasound spatial compound imaging with adjustable aperture controls in accordance with an embodiment of the present invention. The method **400** includes a step **410** of configuring the transducer to transmit and receive an ultrasound beam, a step **420** of generating a frame using the transducer, and a step **430** of combining frames to form a spatially compounded image, as described above.

[0082] In one embodiment of the present invention, step **410** is performed first, followed by step **420**. These two steps are repeated at least once to produce at least two frames. Then step **430** combines at least two frames to form a spatially compounded image. Steps **410** and **420** may be performed in different ways in accordance with the present invention, as described below.

[0083] **FIG. 5** illustrates a flow diagram for a method **500** for ultrasound spatial compound imaging with adjustable aperture controls in accordance with an embodiment of the present invention. The method **500** includes a step **510** of determining a directivity angle, a step **520** of preventing an element from transmitting and/or receiving for a frame, and a step **530** of combining frames to form a spatially compounded image, as described above.

[0084] In one embodiment of the present invention, step **510** is performed first, followed by step **520**. These steps can be repeated at least one more time to produce at least two frames. Then, step **530** combines at least two frames to form a spatially compounded image.

[0085] In step **510**, the directivity angle for at least one element of the transducer array for a given frame of a spatially compounded image is determined. For example, for element **221** of the array **120** of the ultrasound transducer **110**, a directivity angle including **261** or **262** may be determined.

[0086] In step **520**, the element is prevented from transmitting or receiving if the directivity angle for that element for that frame exceeds a threshold angle. For example, the element **221** of the array **120** may be prevented from one or both of transmitting and receiving if the directivity angle, for example, **262**, exceeds a threshold angle. The element **221** may be prevent from transmitting by, for example, powering down the element or not allowing a signal to be communicated to the element. The element **221** may be prevented from receiving by, for example, powering down the element or by ignoring data provided by the element.

[0087] In step **530**, two or more frames can be combined to form a spatially compounded image. For example, the compounding processor **870** may combine two or more frames received from the receive beamforming processor **860** to form a spatially compounded image.

[0088] By determining the directivity angle for each element for each frame, and preventing those elements that exceed the threshold angle from transmitting or receiving, the image quality of all frames can be increased. This can further result in improved contrast resolution for the spatially compounded image.

[0089] **FIG. 6** illustrates a flow diagram for a method **600** for ultrasound spatial compound imaging with adjustable aperture controls using weighting apodizations in accordance with an embodiment of the present invention. The method **600** includes a step **610** of determining a directivity angle, a step **620** of calculating a weighting apodization based on at least a directivity angle, a step **630** of merging a weighting apodization with a standard apodization, a step **640** of applying an apodization to a frame, and a step **650** of combining frames to form a spatially compounded image.

[0090] In one embodiment of the present invention, step **610** is performed first, followed by step **620**, next step **630**, and then step **640**. These steps can be repeated at least one more time to produce at least two frames. Then, step **650** combines at least two frames to form a spatially compounded image.

[0091] In step **610**, the directivity angle for at least one element of the transducer array for a given frame of a spatially compounded image is determined. For example, for element **221** of the array **120** of the ultrasound transducer **110**, a directivity angle including **261** or **262** may be determined.

[0092] In step **620**, a weighting apodization is calculated based on a directivity angle. For example, a directivity angle including **261**, **262** may be used to calculate a weighting apodization. As another example, the directivity angle may be one calculated by step **610**.

[0093] In step **630**, a weighting apodization is merged with a standard apodization to create a final apodization. For example, the weighting apodization calculated in step **620** may be merged with a standard apodization.

[0094] In step **640**, a final apodization is applied to a frame. For example, a final apodization created in step **630** may be applied to a frame.

[0095] In step **650**, two or more frames can be combined to form a spatially compounded image. For example, the compounding processor **870** may combine two or more frames received from the receive beamforming processor **860** to form a spatially compounded image.

[0096] By applying a final apodization to each frame, the image quality of all frames can be increased. This can result in improved contrast resolution for the spatially compounded image.

[0097] **FIG. 7** illustrates a flow diagram for a method **700** for ultrasound spatial compound imaging with adjustable aperture controls related to f-numbers in accordance with an embodiment of the present invention. The method **700** includes a step **710** of determining an f-number for a frame, a step **720** of determining an aperture sized based on at least an f-number, a step **730** of creating a frame using an aperture size, and a step **740** of combining frames to form a spatially compounded image.

[0098] In one embodiment of the present invention, step **710** is performed first, followed by step **720**, and then step **730**. These steps are then repeated at least one more time to produce at least two frames. Then, step **740** combines at least two frames to form a spatially compounded image.

[0099] In step **710**, the f-number for a given frame of a spatially compounded image is determined. A user employing method **700**, for example, may determine the f-number. A user may determine the f-number based on image quality factors such as resolution, uniformity, or the presence of grating lobe artifacts. The f-number may also be based on at least a threshold acceptance angle. For example, the f-number can be large enough so that a majority of directivity angles for the various elements are smaller than the threshold acceptance angle.

[0100] In step **720**, an aperture size is determined based on an f-number. For example, the aperture size may be based on an f-number determined in step **710**.

[0101] In step **730**, ultrasound beams are transmitted and received using the aperture size to form a frame of a spatially compounded image. The aperture size may be based, at least in part, on a focal depth for an ultrasound beam. For example, a frame of a spatially compounded image may be created using one or more aperture sizes determined in step **720**. A standard apodization may also be applied to the frame created in this step.

[0102] In step **740**, two or more frames can be combined to form a spatially compounded image. For example, the compounding processor **870** may combine two or more frames received from the receive beamforming processor **860** to form a spatially compounded image.

[0103] By determining an f-number and aperture size for each frame, the image quality of all frames can be increased. This can further result in improved contrast resolution for the spatially compounded image.

[0104] While the invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from its scope. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A method for ultrasound spatial compound imaging with adjustable aperture controls, said method including:

determining first and second directivity angles of a transducer array element, said first and second angles corresponding to first and second frames of a spatially compounded image, respectively;

preventing said element from at least one of transmitting and receiving an ultrasound beam for at least one of said first frame when said first directivity angle exceeds a threshold angle and said second frame when said second directivity angle exceeds said threshold angle; and

combining at least said first and second frames to form said spatially compounded image.

2. The method of claim 1, wherein said first directivity angle includes an angle between a first propagation path of said beam and a direction perpendicular to a surface of said element and said second directivity angle includes an angle between a second propagation path of said beam and said direction.

3. The method of claim 1, wherein said surface is at least one of a transmission and receiving surface of said element.

4. The method of claim 2, wherein said first and second directivity angles differ.

5. The method of claim 1, wherein said threshold angle is based on at least one or more of a transmit and receive frequency of said beam.

6. A method for ultrasound spatial compound imaging with adjustable aperture controls using weighting apodizations, said method including:

determining first and second directivity angles of a transducer array element, said first and second angles corresponding to first and second frames of a spatially compounded image, respectively;

calculating first and second ultrasound signal weighting apodizations, said first weighting apodization based on at least said first directivity angle, said second weighting apodization based on at least said second directivity angle;

merging said first weighting apodization with a standard signal apodization to create a first final apodization and said second weighting apodization with said standard signal apodization to create a second final apodization;

applying said first and second final apodizations to ultrasound signals based on at least ultrasound beams at least one of transmitted and received during said first and second frames, respectively; and

combining at least said first and second frames to form said spatially compounded image.

7. The method of claim 6, wherein at least one of said first and second directivity angles includes an angle between a propagation path of said beam and a direction perpendicular to said element.

8. The method of claim 6, wherein at least one of said first and second final apodizations is asymmetric.

9. A method for ultrasound spatial compound imaging with adjustable aperture controls related to f-numbers, said method including:

determining first and second f-numbers of a transducer array, said first and second f-numbers corresponding to first and second frames of a spatially compounded image, respectively;

determining first and second aperture sizes of said transducer array for said first and second frames, respectively, said first and second aperture sizes based on at least one or more of said first and second f-numbers;

creating said first and second frames using said first and second aperture sizes, respectively; and

combining at least said first and second frames to form said spatially compounded image.

10. The method of claim 9, wherein at least one of said first and second f-numbers include a ratio of focal depth to aperture size.

11. The method of claim 9, further including applying a standard apodization to at least one of said first and second frames.

12. The method of claim 9, wherein at least one of said first and second f-numbers are based on at least a threshold acceptance angle and a steering angle for an ultrasound beam.

13. The method of claim 12, wherein said threshold acceptance angle is based on at least one or more of a transmit and receive frequency of said ultrasound beam.

14. The method of claim 12, wherein said steering angle is based on at least a user selection.

15. The method of claim 9, wherein said first and second aperture sizes are based on at least a focal depth for an ultrasound beam.

16. An apparatus for ultrasound spatial compounding imaging with adjustable aperture controls, said apparatus including:

a transducer array including at least one element, said element capable of at least one of transmitting and receiving an ultrasound beam for at least one of first and second frames in a spatially compounded image;

an aperture directivity angle processor determining a first directivity angle of said element for said first frame and a second directivity angle of said element for said second frame;

an aperture element control preventing said element from at least one of transmitting and receiving said ultrasound beam for at least one of said first frame when said first directivity angle exceeds a threshold and said second frame when said second directivity angle exceeds said threshold; and

a compounding processor combining at least said first and second frames to form a spatially compounded image.

17. The apparatus of claim 16, wherein said first directivity angle includes an angle between a first propagation path of said beam and a direction perpendicular to a surface of said element and said second directivity angle includes an angle between a second propagation path of said beam and said direction.

18. The apparatus of claim 17, wherein said surface is at least one of a transmission and receiving surface of said element.

19. The apparatus of claim 18, wherein said first and second directivity angles differ.

20. The apparatus of claim 16, wherein said threshold angle is based on at least one or more of a transmit and receive frequency of said beam.

21. An apparatus for ultrasound spatial compounding imaging with adjustable aperture controls using weighting apodizations, said apparatus including:

a transducer array including at least one element capable of transmitting and receiving an ultrasound beam for at least one of first and second frames in a spatially compounded image;

an aperture directivity processor determining a first directivity angle of said element for said first frame and a second directivity angle of said element for said second frame;

an aperture apodization calculation processor calculating first and second ultrasound signal weighting apodizations, said first weighting apodization based on at least said first directivity angle, said second weighting apodization based on at least said second directivity angle;

an aperture apodization merger processor merging said first weighting apodization with a standard signal apodization to create a first final apodization and said second weighting apodization with said standard signal apodization to create a second final apodization;

an aperture apodization application processor applying said first and second final apodizations to ultrasound signals based on at least ultrasound beams at least one of transmitted and received during said first and second frames, respectively; and

a compounding processor combining at least said first and second frames to form a spatially compounded image.

22. The apparatus of claim 21, wherein at least one of said first and second directivity angles includes an angle between a propagation path of said beam and a direction perpendicular to a surface of said element.

23. The apparatus of claim 22, wherein said first and second propagation paths differ.

24. The apparatus of claim 21, wherein at least one of said first and second final apodizations is asymmetric.

25. An apparatus for ultrasound spatial compounding imaging with adjustable aperture controls related to f-numbers, said apparatus including:

a transducer array including at least one element, said element capable of at least one of transmitting and receiving an ultrasound beam for at least one of first and second frames in a spatially compounded image;

an aperture f-number processor determining first and second f-numbers of said array, said first and second f-numbers corresponding to said first and second frames;

an aperture size processor determining first and second aperture sizes of said transducer array for said first and second frames, respectively, said first and second aperture sizes based on at least said first and second f-numbers; and

a compounding processor combining at least said first and second frames to form a spatially compounded image.

26. The apparatus of claim 25, wherein at least one of said first and second f-numbers include a ratio of focal depth to aperture size.

27. The apparatus of claim 25, further including an aperture apodization processor, said aperture apodization processor applying a standard apodization to at least one of said first and second frames.

28. The apparatus of claim 25, wherein at least one of said first and second f-numbers are based on at least a threshold acceptance angle and a steering angle for an ultrasound beam.

29. The apparatus of claim 28, wherein said threshold acceptance angle is based on at least one or more of a transmit and receive frequency of said ultrasound beam.

30. The apparatus of claim 28, wherein said steering angle is based on at least a user selection.

31. The apparatus of claim 25, wherein said first and second aperture sizes are based on at least a focal depth for an ultrasound beam.

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专利名称(译)	用于具有可调孔径控制的超声空间复合成像的方法和设备		
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摘要(译)

公开了一种用于具有可调节孔径控制的超声空间复合成像的方法和设备。该方法和装置可以通过在空间复合图像的每个帧上应用不同的孔径控制来改善所有帧的图像质量。发射和接收孔径控制中的一个或两个可以包括防止换能器阵列的一些元件发射或接收，计算加权变迹以与每个帧的标准变迹相结合，或者基于换能器阵列的f数确定孔径大小。对于每一帧。