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(54) **METHODS AND SYSTEMS FOR ULTRASOUND CONTRAST ENHANCEMENT**

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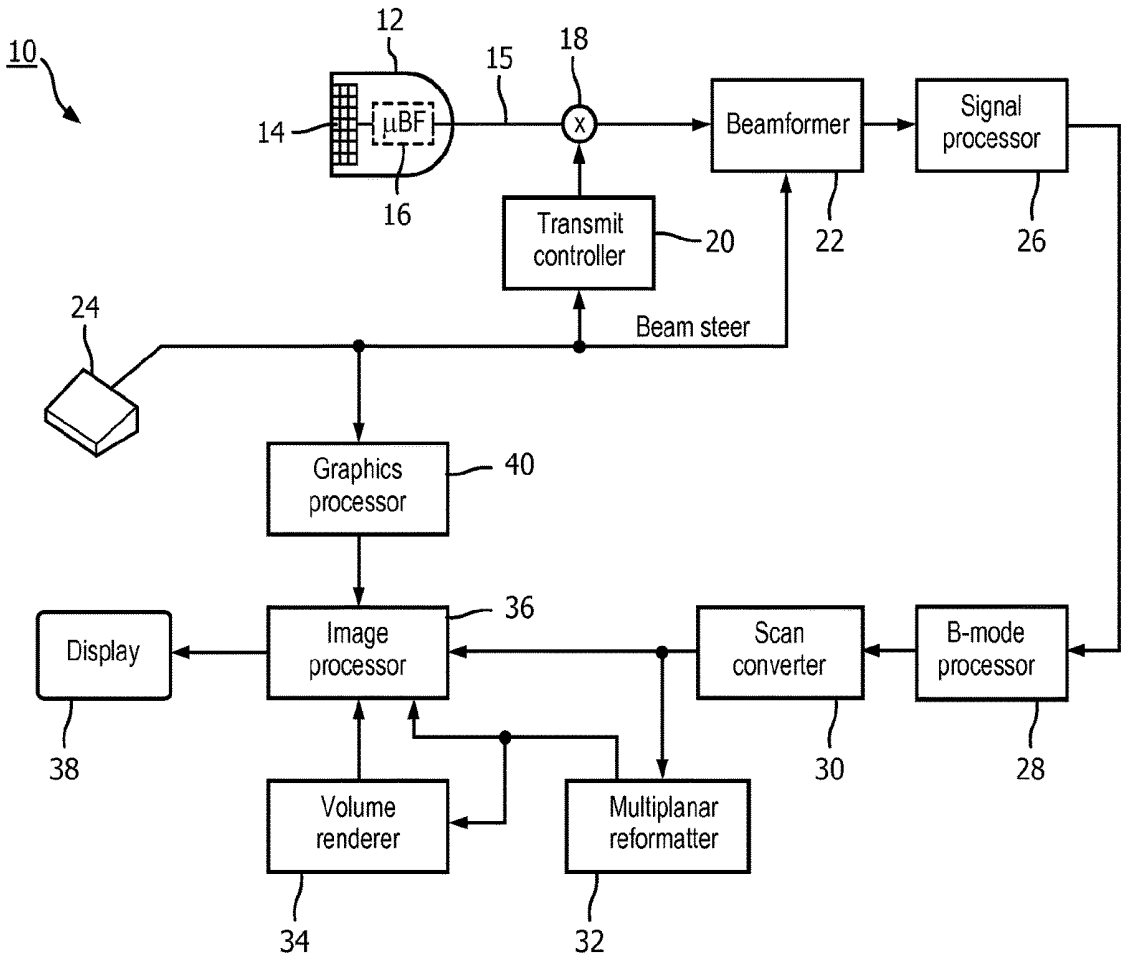
(57) **ABSTRACT**

Systems and methods for suppressing off-axis sidelobes and/or clutter, near-field reverberation clutter, and/or grating lobe contributions are disclosed. A dual apodization with median (DAM) filtering technique is disclosed. The dual apodization technique may include summing aligned channel data with apodization functions (**406**, **412**, **414**) with complementary apertures applied. Median values for a zero function (RF**3**) and the resulting signals (RF**1**, RF**2**) from the complementary apertures are determined to generate a median value signal (**416**, MVS). The median value signal is used to generate an ultrasound image with enhanced image contrast. A method of image smoothing of the ultrasound image with enhanced image contrast is also disclosed. The smoothed image may include low frequency components of the ultrasound image with enhanced image contrast and high frequency components of an original image.



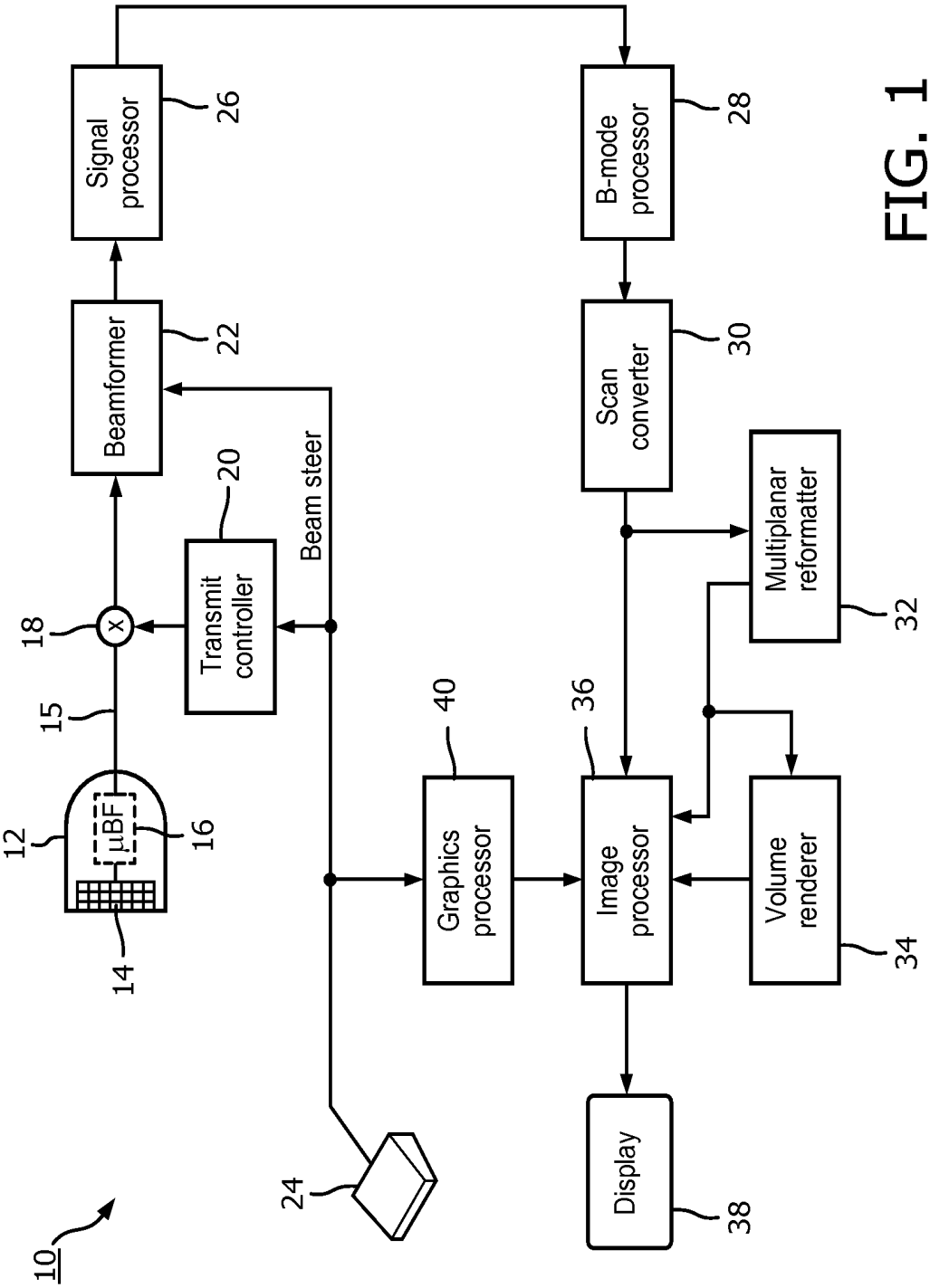

Signal processor
26
B-mode processor
28
Beamformer
22
Scan converter
30
Beam steer
20
Transmit controller
Multiplanar reformatter
32
18
15
12
µBF
16
14
40
36
Graphics processor
Image processor
Volume renderer
34
24
Display
38
10

FIG. 1

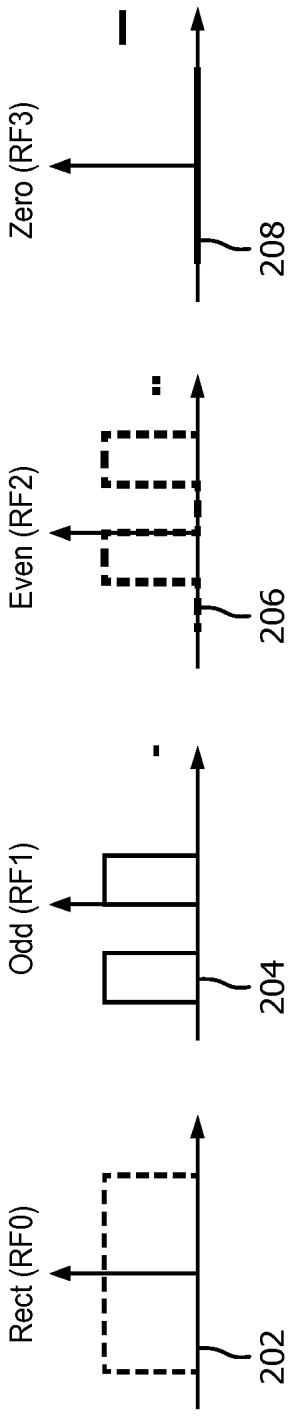


FIG. 2

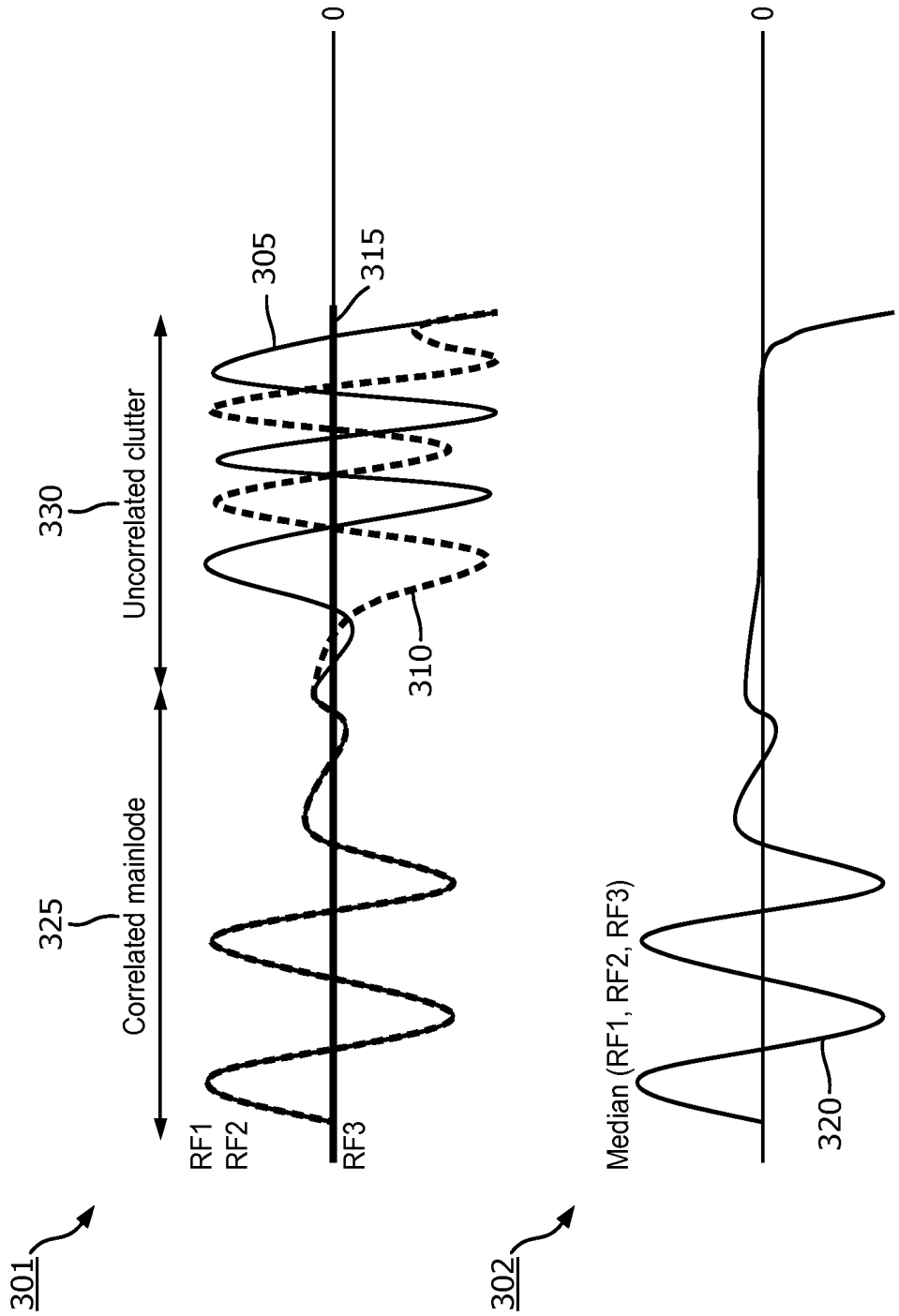

301
302
RF1
RF2
RF3
0
305
315
310
330
Uncorrelated clutter
325
Correlated mainlode
Median (RF1, RF2, RF3)
0
320

FIG. 3

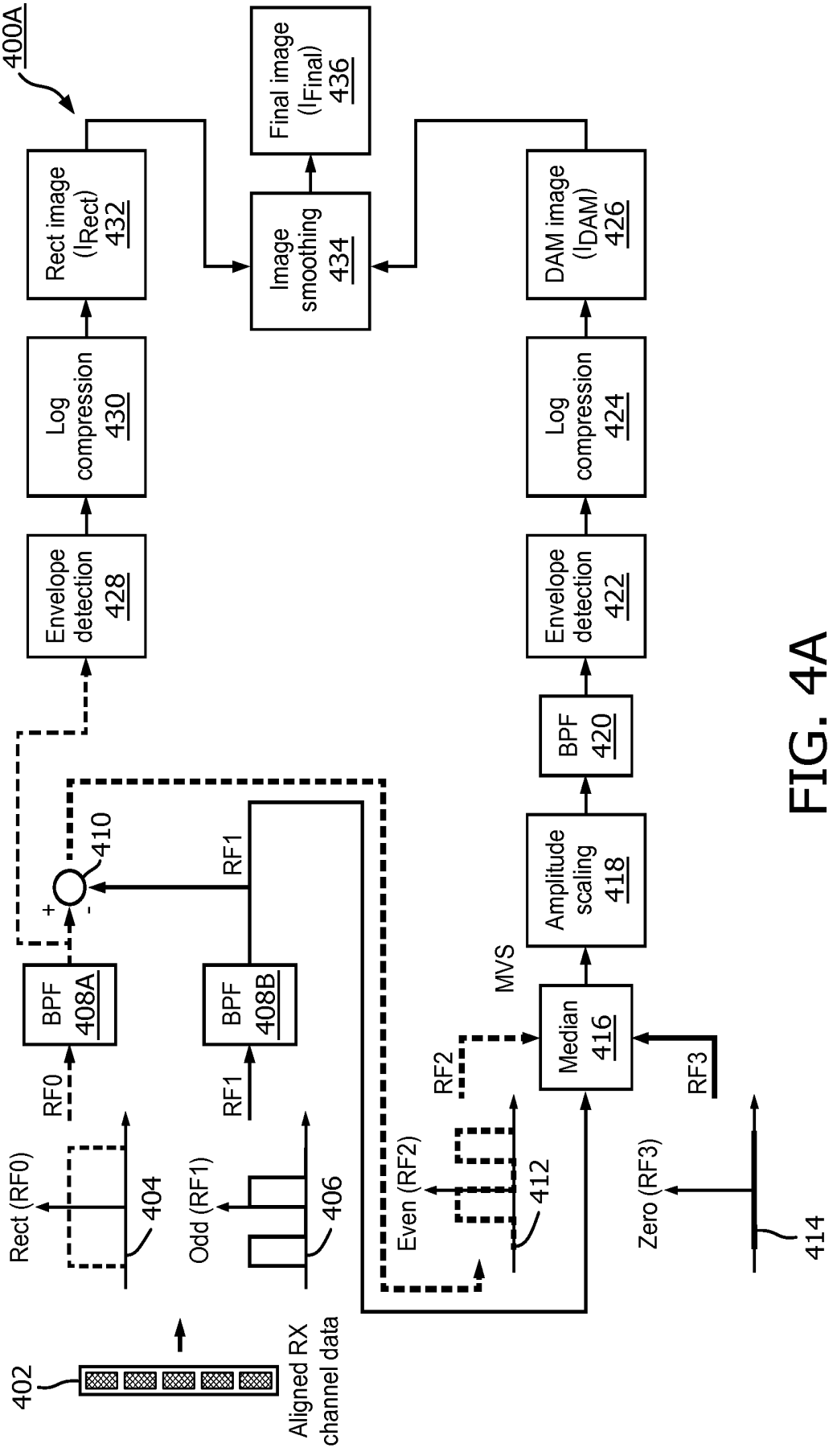

400A
Final image (IFinal) 436
Rect image (IRect) 432
Image smoothing 434
DAM image (IDAM) 426
Log compression 430
Log compression 424
Envelope detection 428
Envelope detection 422
BPF 420
410
RF1
BPF 408A
BPF 408B
Amplitude scaling 418
MVS
RF0
RF1
RF2
Median 416
RF3
Rect (RF0)
404
Odd (RF1)
406
Even (RF2)
412
Zero (RF3)
414
402
Aligned RX channel data

FIG. 4A

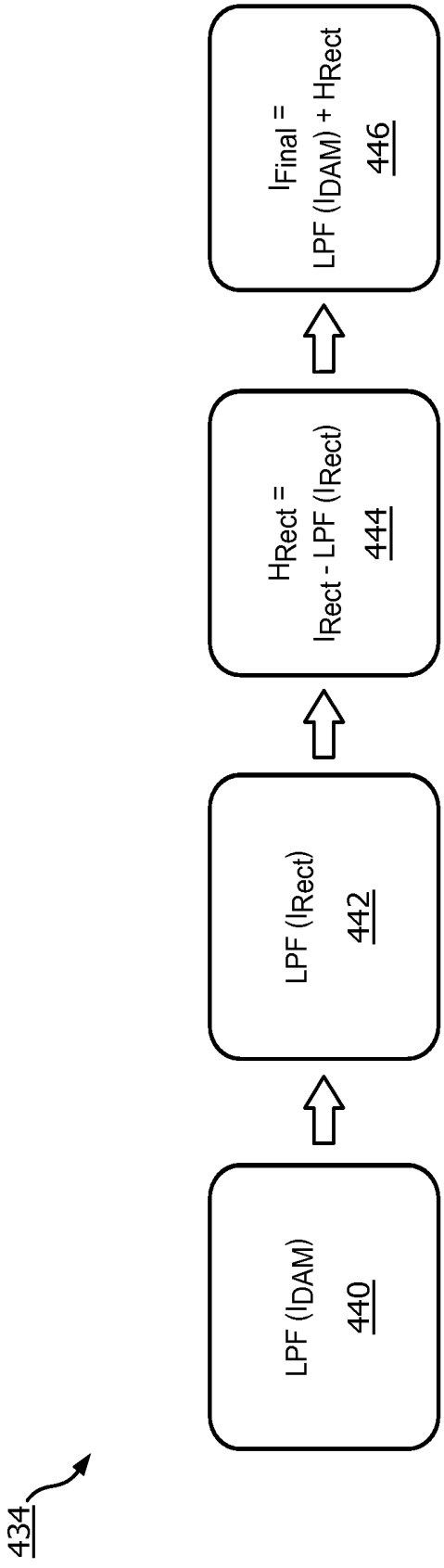

434
LPF (IDAM)
440
LPF (IRect)
442
HRect =
IRect - LPF (IRect)
444
IFinal =
LPF (IDAM) + HRect
446

FIG. 4B

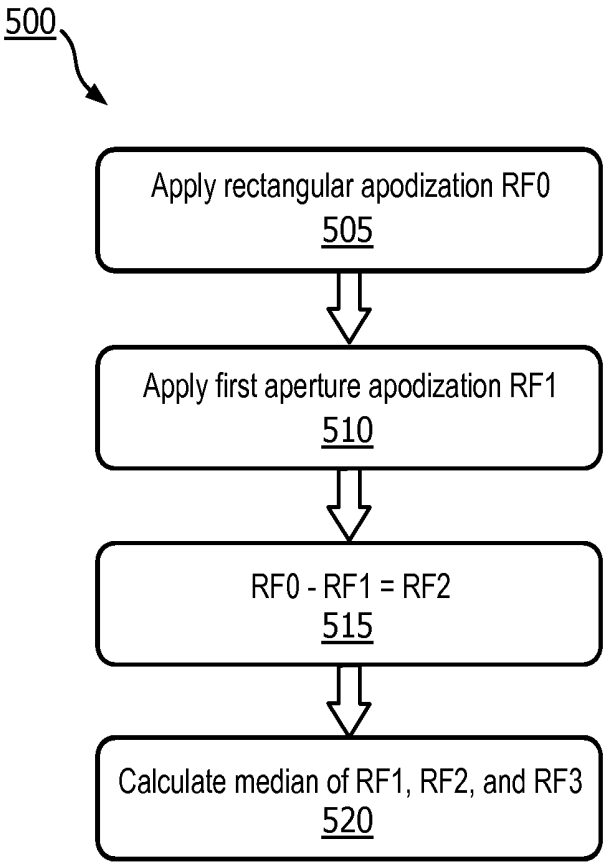

500
Apply rectangular apodization RF0
505
Apply first aperture apodization RF1
510
RF0 - RF1 = RF2
515
Calculate median of RF1, RF2, and RF3
520

FIG. 5

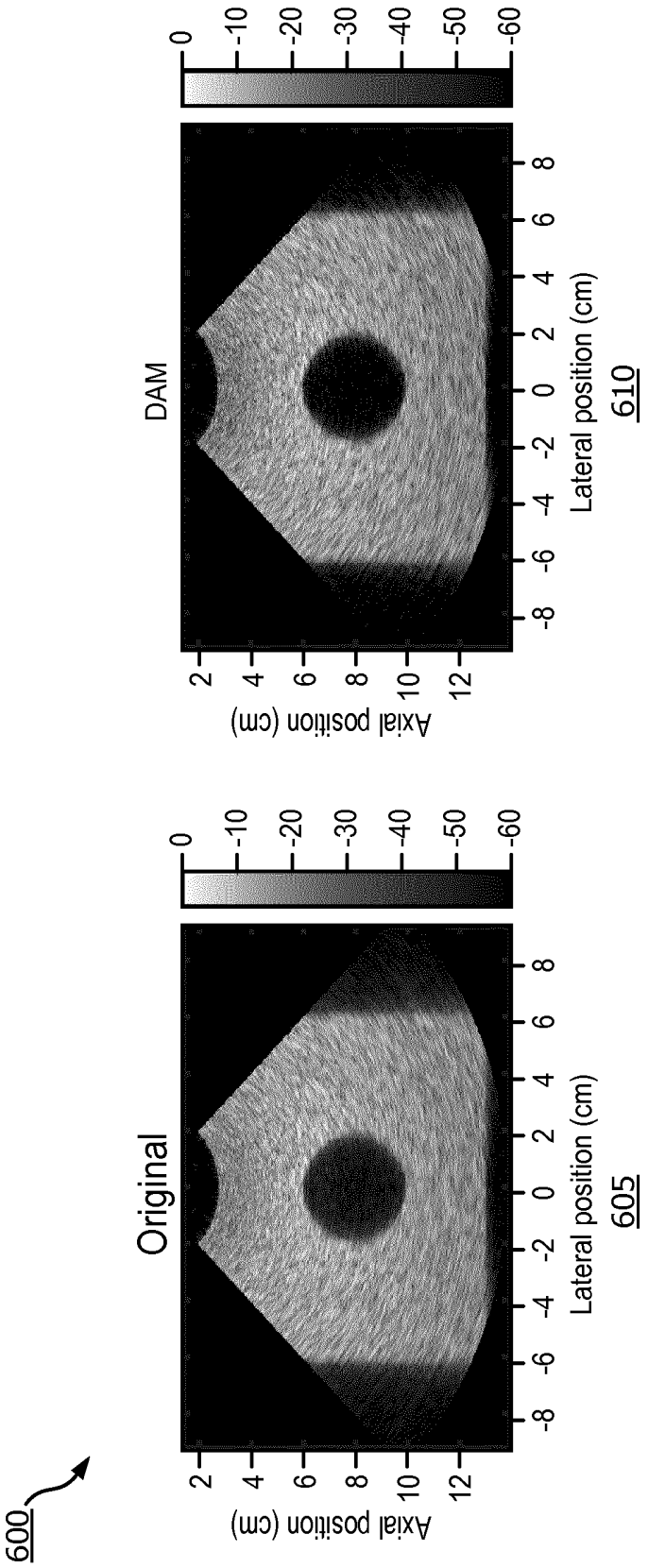

600
Original
Axial position (cm)
Lateral position (cm)
605
DAM
Axial position (cm)
Lateral position (cm)
610

FIG. 6

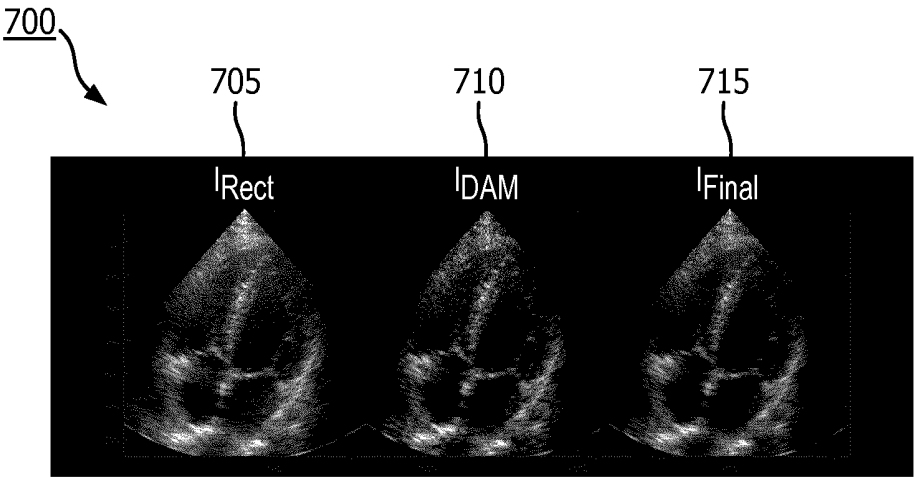


FIG. 7

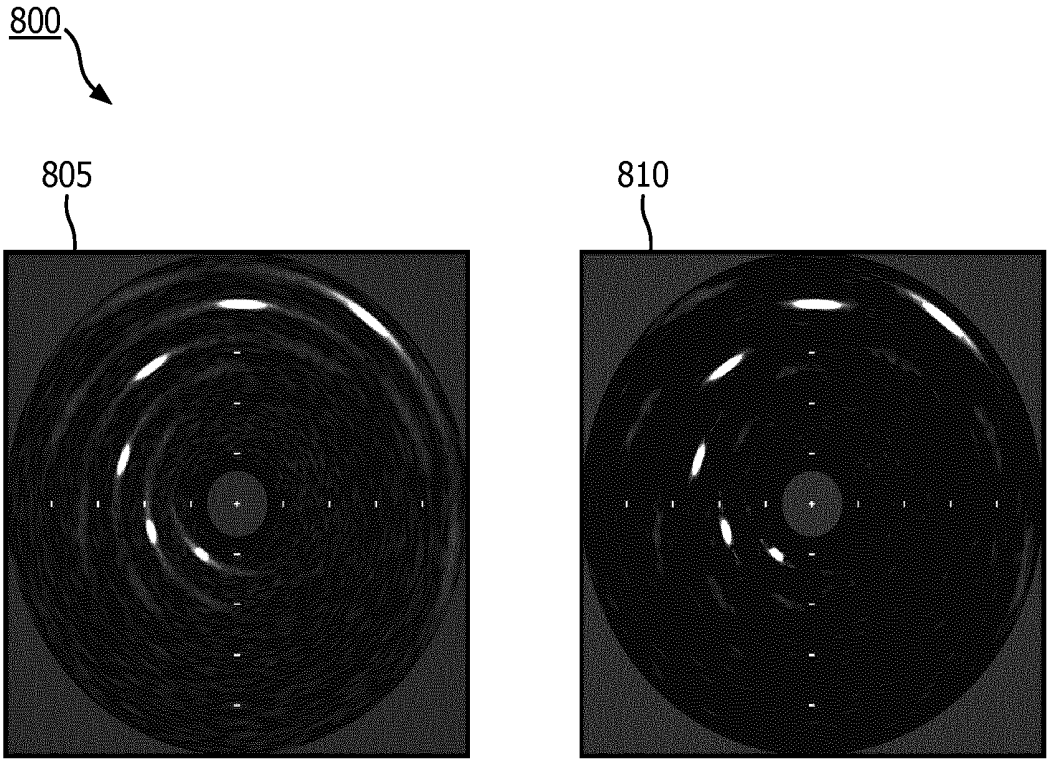


FIG. 8

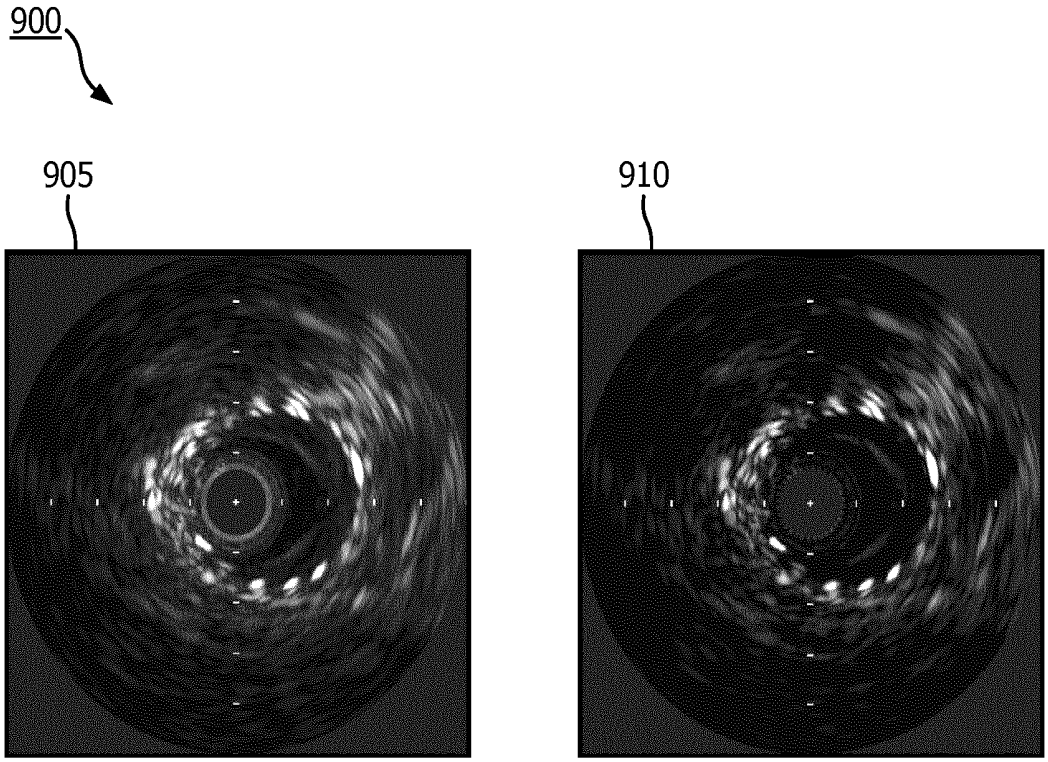


FIG. 9

METHODS AND SYSTEMS FOR ULTRASOUND CONTRAST ENHANCEMENT

RELATED APPLICATION

[0001] This application claims the benefit of and priority to U.S. Provisional No. 62/562,093, filed Sep. 22, 2017, which is incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] This application is directed to dual apodization with median filtering techniques.

[0003] Specifically, this application is directed to dual apodization with median filtering for contrast enhancement in ultrasound images.

BACKGROUND

[0004] In medical ultrasound, image contrast is often compromised as a result of acoustic clutter due to off-axis scattering, reverberation clutter due to near-field anatomical structures, and random electronic noise. In order to address this problem, several adaptive weighting techniques have been proposed in the medical ultrasound community.

[0005] Well-known adaptive weighting techniques such as the coherence factor (CF), the generalized coherence factor (GCF), the phase coherence factor (PCF) and the short-lag spatial coherence (SLSC) technique have been proposed, but they all require access to per-channel data to compute a weighting mask, which is used to weigh down the contributions from acoustic clutter and reverberation clutter from the original image. The required access to per-channel data may make hardware implementations of these techniques difficult, especially on pre-existing ultrasound systems.

SUMMARY

[0006] The systems, methods, and/or apparatuses described herein may provide improvements over previous adaptive weighting techniques and/or other dual apodization techniques. The dual apodization with median (DAM) technique described herein may utilize two complementary apertures which may reduce and/or suppress off-axis signals. An aperture shift introduced by complementary apodizations may cause off-axis signals to be out of phase between the two apertures. Taking the median signal between the two apertures and a zero value may reduce and/or eliminate signals that are out of phase between the two apertures. Signals out of phase between the two apertures may be off-axis signals that may contribute to decreased image contrast. Thus, reduction and/or elimination of these out of phase signals may provide improved image contrast.

[0007] As described herein, the DAM technique may filter out undesired clutter contributions by taking the median value of the three values at each position: 1) the radio frequency (RF) signal from an odd aperture; 2) the RF signal from an even aperture; and 3) the RF signal=0 or near 0 (e.g., 0.1, 0.01, 0.001). The terms even and odd apertures as used herein refer to complementary apertures. This technique may eliminate the need to access per-channel data and/or to perform cross-correlation computation with a predetermined two-dimensional kernel, and other image processing steps on the weighting mask such as thresholding and spatial smoothing, all of which are associated with at least one or more parameters that must be optimized empirically.

[0008] According to an exemplary embodiment of the disclosure, a method may include generating a first signal equivalent to summing aligned channel data with an apodization function with a first aperture applied, wherein the aligned channel data corresponds to ultrasound data, generating a second signal equivalent to summing the aligned channel data with the apodization function with a second aperture applied, wherein the second aperture is complementary to the first aperture, determining median values of the first signal, the second signal, and a third signal to generate a median value signal, wherein the third signal is constant value signal, wherein the constant value is zero or near zero, and generating an ultrasound image, based at least in part, on the median value signal.

[0009] According to some exemplary embodiments of the disclosure, the method may further include generating an original image from the aligned channel data, applying a first spatial low pass filter to the original image to generate a low frequency original image, subtracting the low frequency original image from the original image to generate a high frequency original image, applying a second spatial low pass filter to the ultrasound image to generate a low frequency ultrasound image, and summing the high frequency original image and the low frequency ultrasound image to generate a final image.

[0010] According to another exemplary embodiment of the disclosure, an ultrasound imaging system may include an ultrasound transducer array which may be configured to transmit and receive ultrasound signals, a plurality of channels operatively coupled to the ultrasound transducer which may be configured to transmit channel data based, at least in part, on the received ultrasound signals, a beamformer operably coupled to the plurality of channels, the beamformer may be configured to align the channel data, and a signal processor operatively coupled to the beamformer. The signal processor may be configured to receive aligned channel data from the beamformer, generate a first signal equivalent to the aligned channel data summed with an apodization function with a first aperture applied, generate a second signal equivalent to the aligned channel data summed with the apodization function with a second aperture applied, wherein the second aperture is complementary to the first aperture, determine median values of the first signal, the second signal, and a third signal to generate a median value signal, wherein the third signal is a constant value signal, wherein the constant value is zero or near zero, and generate an ultrasound image, based at least in part, on the median value signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a block diagram of an ultrasound imaging system according to principles of the present disclosure.

[0012] FIG. **2** illustrates examples of four apodization functions according to principles of the present disclosure.

[0013] FIG. **3** illustrates a plot of an example of channel data after passing through an odd apodization function, an even apodization function, and a zero value function and a plot of a median of the three apodization functions according to embodiments of the present disclosure.

[0014] FIG. **4**A illustrates an overview of the dual apodization median (DAM) filtering technique according to principles of the present disclosure.

[0015] FIG. **4**B illustrates the image smoothing of FIG. **4**A in more detail.

[0016] FIG. **5** is a flowchart of a method according to principles of the present disclosure.

[0017] FIG. **6** shows images of a simulated phantom containing a **40**mm-diameter anechoic cyst lesion according to principles of the present disclosure

[0018] FIG. **7** shows images of an apical **4**-chamber view of a heart from a healthy volunteer according to principles of the present disclosure.

[0019] FIG. **8** shows intravenous ultrasound (IVUS) images of a simulated phantom containing six point scatterers and background noise according to principles of the present disclosure.

[0020] FIG. **9** shows IVUS images of a stent according to principles of the present disclosure.

DETAILED DESCRIPTION

[0021] The following description of exemplary embodiments is merely exemplary in nature and is in no way intended to limit the invention or its applications or uses. In the following detailed description of embodiments of the present systems and methods, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the described systems and methods may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the presently disclosed systems and methods, and it is to be understood that other embodiments may be utilized and that structural and logical changes may be made without departing from the spirit and scope of the present system.

[0022] The following detailed description is therefore not to be taken in a limiting sense, and the scope of the present system is defined only by the appended claims. The leading digit(s) of the reference numbers in the figures herein typically correspond to the figure number, with the exception that identical components which appear in multiple figures are identified by the same reference numbers. Moreover, for the purpose of clarity, detailed descriptions of certain features will not be discussed when they would be apparent to those with skill in the art so as not to obscure the description of the present system.

[0023] Apodization-based adaptive weighting techniques may generate weighting masks without having access to the per-channel data and may be easier to implement from a hardware perspective compared to other adaptive weighting techniques. For example, a technique called the dual apodization with cross-correlation (DAX) applies a dual-apodization function followed by cross-correlation of the two functions. An example of a DAX technique may be found in C. H. Seo, and J. T. Yen, "Sidelobe suppression in ultrasound imaging using dual apodization with cross-correlation", IEEE Trans. Ultrason. Ferroelectr. Freq. Control, vol. 55, no. 10, 2198-2210, October 2008. However, DAX techniques require additional cross-correlation computations with a pre-determined two-dimensional kernel, and image processing of the weighting mask such as thresholding and spatial smoothing. In addition to high computational load, all of the image processing steps of the DAX method require setting at least one parameter that must be optimized empirically. Empirical optimization may require extensive experiments by an ultrasound system developer and/or an end user (e.g., ultrasound technician, clinician) prior to imaging. In some cases, empirical optimization may require subjective determinations by a human user, which may be time consuming and/or introduce inconsistencies in performance between users.

[0024] According to principles of the present disclosure, a filtering technique called dual apodization with median (DAM) may reduce and/or eliminate noise in ultrasound images including noise contributions from off-axis sidelobes/clutter, near-field reverberation clutter, and/or grating lobes. The DAM technique may be performed in the beamspace domain by taking the median value of three values at each position in an ultrasound image: the radio frequency (RF) signals from two complementary apertures (e.g., an odd aperture and an even aperture) and a zero signal or near-zero signal. The DAM technique may not require significant additional hardware implementation. The DAM technique may eliminate the need to perform cross-correlation computation and/or additional image processing steps. This may improve image processing time and/or reduce hardware requirements of an imaging system.

[0025] As described herein, an ultrasound imaging system according to principles of the disclosure may include an ultrasound transducer array which may be configured to transmit and receive ultrasound signals. A plurality of channels may be operatively coupled to the ultrasound transducer. The channels may be configured to transmit channel data based, at least in part, on the received ultrasound signals (e.g., echos). The channel data may be radio frequency (RF) data in some embodiments. A beamformer may be operably coupled to the plurality of channels and configured to align the channel data. Alignment may include delaying and/or geometrically aligning the channel data from the channels. A signal processor may be operatively coupled to the beamformer. The signal processor may be configured to receive aligned channel data from the beamformer, generate a first signal equivalent to the aligned channel data summed with an apodization function with a first aperture applied and generate a second signal equivalent to the aligned channel data summed with the apodization function with a second aperture applied. The second aperture may be complementary to the first aperture. The signal processor may determine median values of the first signal, the second signal, and a third signal to generate a median value signal. The third signal may be a constant value signal. The constant value may be zero or near zero. The signal processor may generate an ultrasound image, based at least in part, on the median value signal.. . This ultrasound image may have improved contrast compared to an ultrasound image generated by applying only a rectangular apodization function.

[0026] Referring to FIG. **1**, an ultrasound imaging system **10** constructed in accordance with the principles of the present disclosure is shown in block diagram form. In the ultrasonic diagnostic imaging system of FIG. **1**, an ultrasound probe **12** includes a transducer array **14** for transmitting ultrasonic waves and receiving echo information. A variety of transducer arrays are well known in the art, e.g., linear arrays, convex arrays or phased arrays. The transducer array **14**, for example, can include a two dimensional array (as shown) of transducer elements capable of scanning in both elevation and azimuth dimensions for 2D and/or 3D imaging. The transducer elements of transducer array **14** may be coupled via channels **15** to a microbeamformer **16** in the probe **12** in some embodiments. A separate channel may be provided for each transducer element of the transducer array **14** or for each patch of transducer elements. However,

for clarity of the diagram, only one line is illustrated for the channels **15** in FIG. **1**. The microbeamformer **16** may control transmission and reception of signals by the transducer elements in the array. In this example, the microbeamformer **16** is coupled by the probe cable to a transmit/receive (T/R) switch **18**, which switches between transmission and reception and protects the main beamformer **22** from high energy transmit signals. In some embodiments, the T/R switch **18** and other elements in the system can be included in the transducer probe rather than in a separate ultrasound system base. The transmission of ultrasonic beams from the transducer array **14** under control of the microbeamformer **16** is directed by the transmit controller **20** coupled to the T/R switch **18** and the beamformer **22**, which receives input from the user's operation of the user interface or control panel **24**. One of the functions controlled by the transmit controller **20** is the direction in which beams are steered. Beams may be steered straight ahead from (orthogonal to) the transducer array, or at different angles for a wider field of view. The microbeamformer **16** may perform some alignment (e.g., delay and/or geometric alignment) of the radio frequency (RF) signals (e.g., channel data) from the channels **15**. The signals produced by the microbeamformer **16** may be coupled to a main beamformer **22** for further alignment.

[0027] In some embodiments, the microbeamformer **16** is omitted. The transmit controller **20** may control the transducer array **14** directly through the T/R switch **18**. Data from the transducer array **14** elements may be transmitted via channels **15** to the main beamformer **22** for alignment.

[0028] The channel data aligned by the beamformer **22** are coupled to a signal processor **26**. The signal processor **26** can process the aligned channel data in various ways, such as bandpass filtering, decimation, I and Q component separation, and harmonic signal separation. The signal processor **26** may also perform additional signal enhancement such as speckle reduction, signal compounding, and noise elimination. According to principles of the present disclosure, the signal processor may perform a dual apodization with median (DAM) filtering technique on the channel data aligned by the beamformer **22**. The signal processor **26** may be implemented in hardware (e.g., Application Specific Integrated Circuit (ASIC)), software, or a combination thereof Although shown as a single unit in FIG. **1**, in some embodiments, the signal processor **26** may be implemented with multiple processors.

[0029] The processed signals generated by the signal processor **26** are coupled to a B mode processor **28**, which can employ amplitude detection for the imaging of structures in the body. The signals produced by the B mode processor are coupled to a scan converter **30** and a multiplanar reformatter **32**. The scan converter **30** arranges the echo signals in the spatial relationship from which they were received in a desired image format. For instance, the scan converter **30** may arrange the echo signal into a two dimensional (2D) sector-shaped format, or a pyramidal three dimensional (3D) image. The multiplanar reformatter **32** can convert echoes which are received from points in a common plane in a volumetric region of the body into an ultrasonic image of that plane, as described in U.S. Pat. No. 6,443,896 (Detmer). A volume renderer **34** converts the echo signals of a 3D data set into a projected 3D image as viewed from a given reference point, e.g., as described in U.S. Pat. No. 6,530,885 (Entrekin et al.) The 2D or 3D images are coupled from the scan converter **30**, multiplanar reformatter **32**, and volume renderer **34** to an image processor **36** for further enhancement, buffering and temporary storage for display on an image display **38**. The graphics processor **40** can generate graphic overlays for display with the ultrasound images. These graphic overlays can contain, e.g., standard identifying information such as patient name, date and time of the image, imaging parameters, and the like. For these purposes the graphics processor receives input from the user interface **24**, such as a typed patient name. The user interface can also be coupled to the multiplanar reformatter **32** for selection and control of a display of multiple multiplanar reformatted (MPR) images.

[0030] Returning to the DAM filtering technique, which may be performed by a signal processor (e.g., signal processor **26**) or processors, a method according to principles of the present disclosure may include generating a first signal equivalent to summing aligned channel data with an apodization function with a first aperture applied. The aligned channel data may correspond to ultrasound data. The method may further include generating a second signal equivalent to summing the aligned channel data with the apodization function with a second aperture applied, which may be complementary to the first aperture. The method may further include determining median values of the first signal, the second signal, and a third signal to generate a median value signal. The third signal may be a constant value signal, which may be zero or near zero. . The method may further include generating an ultrasound image, based at least in part, on the median value signal.

[0031] In some embodiments, additional steps may be performed as part of the method, which may include generating an original image from the aligned channel data, applying a first spatial low pass filter to the original image to generate a low frequency original image, subtracting the low frequency original image from the original image to generate a high frequency original image, applying a second spatial low pass filter to the ultrasound image to generate a low frequency ultrasound image, and summing the high frequency original image and the low frequency ultrasound image to generate a final image. This may produce an image with improved contrast that retains details such as speckle pattern from the original image.

[0032] FIG. **2** illustrates examples of four apodization functions **202**, **204**, **206**, and **208** according to principles of the present disclosure. Apodization functions determine the weight given to data from each channel during summing to generate a beamsum signal. As mentioned previously in reference to FIG. **1**, each channel may correspond to a transducer element in a transducer array. The rectangular Rect apodization function **202** gives equal weight to all channels. Thus, in some embodiments, the signal from each transducer element is equally weighted. At the opposite end of the spectrum, the Zero apodization function **208** gives no weight (e.g., masks) the data from all of the channels. With the Zero apodization function **208**, all transducer elements may be masked (e.g., off). Apodization functions Odd **204** and Even **206** alternate in weighting some channels while masking others. Apodization function Odd **204** may be generated by applying an odd aperture to an apodization function and apodization function Even **206** may be generated by applying an even aperture to an apodization function. In some embodiments, such as the examples shown in FIG. **2**, the odd and even apodization functions may uniformly weight all of the channels not masked. The apodiza-

tion function with an odd aperture **204** may weight the opposite channels as the apodization function with an even aperture **206**. For example, the apodization function **204** may weight odd numbered channels and mask even numbered channels while the apodization function **206** may weight even numbered channels and mask odd numbered channels.

[0033] Although odd and even channels or transducer elements are used as examples, the terms "odd" and "even" apodization functions as used herein refer to two complementary apodization functions and do not necessarily correspond to odd or even numbered channels and/or transducer elements. Furthermore, the even and odd aperture apodization functions are not limited to alternating between single channels, but may alternate between groups of multiple channels (e.g., two, three, four). The multiple channels may be adjacent (e.g., consecutive) to one another. This may correspond to transducer elements that are adjacent to one another in some embodiments. Alternating between single channels may correspond to an apodization function having a short period whereas the period of the apodization function becomes longer as the number of multiple channels included in the groups increases. As the period of the even and odd apodization functions increase, the resulting DAM filtering will become more aggressive. The period may be pre-set in an ultrasound imaging system and/or may be selected by a user via a user interface (e.g., user interface **24**).

[0034] FIG. **3** illustrates a plot **301** of an example of aligned channel data after passing through an odd apodization function and an even apodization function. Plot **301** further includes a constant zero function. FIG. **3** further illustrates a plot **302** of a median of the signals generated by the three functions. In some embodiments, the aligned channel data may have been provided by a beamformer (e.g., beamformer **22**) to a signal processor (e.g., signal processor **26**), which may have summed the aligned channel data with the apodization functions and/or performed the median operation. According to principles of the present disclosure, when a complementary pair of apertures (e.g., odd and even) are applied to apodization functions to form two independent beamsum RF signals (RF**1** **305** and RF**2** **310** in FIG. **3**) from the channel data, they may be highly correlated if the signals are from the on-axis mainlobe, as shown in the correlated mainlobe region **325**. However, the signals may be highly uncorrelated if the signals are from off-axis regions, as shown in the uncorrelated clutter region **330**. This is because the odd and even apertures have a large effective pitch, introducing grating lobes that have a phase difference of half a wavelength. The periods of the even and odd apodization functions, in addition to adjusting the aggressiveness of the filter, may also change the position of the introduced grating lobes.

[0035] After introducing a third signal RF**3** **315**, which is zero or near zero for all values, a new RF signal (e.g., median value signal) **320** may be obtained by taking the median value of RF**1** **305**, RF**2** **310**, and RF**3** **315**. In the correlated mainlobe region **325**, median value signal **320** results in a new signal very similar to RF**1** **305** or RF**2** **310**. In the uncorrelated clutter region **330**, median value signal **320** results in a signal padded with zeroes. This may reduce noise in an image generated from the median signal. If the phase difference between RF**1** and RF**2** is between CP and **18**CP, median value signal **320** may produce a new signal which is smaller in amplitude when compared with RF**1** **305** and RF**2** **310** but may not resemble either.

[0036] FIG. **4**A illustrates an overview **400**A of the dual apodization median (DAM) filtering technique according to principles of the present disclosure. The DAM filtering technique may be performed by a signal processor (e.g., signal processor **26**) or multiple signal processors in some embodiments. The signal processor may be implemented as hardware, software, or a combination thereof. From the aligned channel data **402** received from a beamformer (e.g., beamformer **22** and/or microbeamformer **16**), beamsum radio frequency (RF) signals may be generated by summing aligned channel data with apodization functions as described herein. A first beamsum RF signal RF**0** may be obtained by summing aligned channel data with a rectangular apodization function **404** and a second beamsum RF signal RF**1** may be obtained by summing aligned channel data with an apodization function with an odd aperture **406** applied. Signals RF**0** and RF**1** may be passed through a bandpass filters **408**A and **408**B. The signals RF**0** and RF**1** may be combined at block **410** where RF**1** may be subtracted from RF**0** to derive another beamsum RF signal, RF**2**, which may correspond to a beamsum signal generated from summing aligned channel data **402** with an apodization function with the complementary even aperture **412** applied. Alternatively, RF**2** may be obtained by directly summing the aligned channel data **402**with an apodization function with an even aperture applied. However, this may require implementing an additional receive apodization and may require an additional bandpass filter for the signal generated from the additional apodization function.

[0037] After obtaining the RF**1** and RF**2**, at block **416**, the median value between RF**1**, RF**2**, and zero (RF**3**) **414** may be computed to obtain a new RF signal referred to here as a median value signal MVS. The median value is found for every depth for every lateral location in the ultrasound image. In some embodiments, RF**3** may be set to a value other than zero. For example, RF**3** may be set to a value close to zero (e.g., 0.1, 0.01, 0.001) to compensate for an offset in the imaging system. The value of RF**3** may be pre-set in an ultrasound imaging system and/or may be set by a user via a user interface (e.g., user interface **24**).

[0038] The beamsum RF signals generated by complementary apodization functions may not sum the aligned channel data from all the channels. This may cause the resulting MVS to have a different amplitude than RF**0**. In the example shown in FIG. **4**A, RF**1** and RF**2** use only half of the channel data used in RF**0**, thus the amplitude of RF**1** and RF**2** may be reduced by approximately a factor of two. Hence, the amplitude ofthe new RF signal MVS generated by the median operation performed by block **416** is also smaller by a factor of two. This amplitude change may be accounted for by a scaling operation at block **418** on the median value signal MVS. The scaling operation at block **418** may be followed by another bandpass filter **420** to remove any frequency components outside of the transducer bandwidth that may have been introduced by the nonlinear median operation performed by block **416**. The bandpass filtered RF signal may then be envelope-detected at block **422** and log-compressed at block **424** to yield a DAM image **426**. As shown in FIG. **4**A, envelope detection at block **428** and log compression at block **430** are also processes applied to form the original image I_{Reset} **432** (e.g., an image formed without using the DAM technique).

[0039] Although the DAM image, I_{DAM} **426** has improved contrast and may be sufficient to replace the original image I_{Rect} **432**, some tissue signals may sometimes be lost and thus, the speckle texture may be adversely affected in some cases. This may create a blocky appearance, especially for some in vivo images. To alleviate this possible issue, a multiscale image decomposition image processing technique may optionally be implemented for image smoothing **434**. The technique may form a final image I_{Final} **436** by combining the high spatial frequency components of the original image I_{Rect} formed with rectangular apodization and the low spatial frequency components of the DAM image.

[0040] FIG. **4**B illustrates the image smoothing **434** in more detail. The DAM image IDAm **426** is low pass filtered by a spatial low pass filter at Block **440** and the original image IRect **432** is also low pass filtered by a spatial low pass at Block **442**. This may generate low frequency (e.g., blurred) I_{DAM} and I_{Rect} images. Blocks **440** and **442** may be performed in the opposite order or simultaneously. The low-pass filtered original image LPF(I_{Rect}) is subtracted from the original image to obtain a high frequency original image H_{Rect} at Block **444**. Finally, the low pass filtered DAM image LPF(I_{DAM}) and H_{Rect} are summed to acquire the final image I_{Final} **436** at Block **446**. In other words, the final image may comprise the low frequency components of the I_{DAM} image and the high frequency components (e.g., speckle) of the original image I_{Rect}. After image smoothing, the final image may provide enhanced image contrast of the DAM technique while preserving the speckle pattern of the original image.

[0041] The functions (e.g., Rect **404** and Odd **406**), filters (e.g., **408**A, **408**B, **420**), and/or blocks (e.g., **410**, **416**, **418**) shown in FIGS. **4**A and **4**B may be implemented in hardware, software, and/or a combination thereof. For example, bandpass filter **408**A may be implemented as a circuit or as a digital filter. In another example, block **416** may be implemented as an ASIC or as a software function. Other implementations and combinations of implementations may be used for the functions, filters, and/or blocks shown in FIGS. **4**A and **4**B.

[0042] FIG. **5** is a flowchart **500** of a method according to principles of the present disclosure. Flowchart **500** summarizes the steps of the DAM filtering technique described above in reference to FIGS. **1**-**4**. The method in FIG. **5** may be performed by a signal processor, such as the signal processor **26** of FIG. **1** and/or the signal processor described in reference to FIG. **4**A and/or FIG. **4**B. At Step **505**, aligned channel data is summed with a rectangular apodization function to obtain signal RF**0**. The aligned channel data may correspond to data for an ultrasound image. At Step **510**, the aligned channel data is summed with an apodization function with a first aperture applied to obtain signal RF**1**. The first aperture may mask every other element, every two elements, or have a longer period. The longer the period, the more aggressive the DAM filtering will be. Steps **505** and **510** may be performed in reverse order or simultaneously. Bandpass filtering may be applied to RF**0** and RF**1**. At Step **515**, signal RF**1** is subtracted from RF**0** to derive signal RF**2**. Signal RF**2** is equivalent to the aligned channel data summed by an apodization function having an aperture complementary to the first aperture applied. The complementary apertures RF**1** and RF**2** may be referred to as odd and even apertures, respectively. Alternatively, at Step **515**, the aligned channel data may be summed by an apodization function having an aperture complementary to the first aperture applied. In this embodiment, Step **515** may be performed at the same time or prior to Step **505** and/or Step **510**. When Step **515** includes directly acquiring the beam-sum RF signal from the complementary aperture, Step **505** may be omitted in some embodiments (e.g., when the DAM image will not be combined with an original image). The median value of signals RF**1**, RF**2**, and RF**3** is calculated at Step **520**. Signal RF**3** is a constant signal of zero value. Alternatively, RF**3** may be a constant signal with a value near zero (e.g., 0.001, 0.01) to compensate for an offset in a system. The median value is calculated for every position and depth in the ultrasound image to generate a median value signal.

[0043] After the DAM filtering technique shown in FIG. **5** has been completed, the amplitude of the DAM filtered signal (e.g., all of the calculated median values, the median value signal) may be scaled to compensate for the amplitude reduction introduced by the even and odd aperture apodization functions. The scaled signal may be bandpass filtered to remove any frequency components that may have been introduced by the median operation at Step **520**. The bandpass filtered signal may then undergo typical signal processing including envelope detection and log compression to acquire a DAM filtered image. As discussed previously in reference to FIGS. **4**A and **4**B, the DAM image may be provided and/or a combined original and DAM image may be provided. The image may be provided to a display and/or a computer readable memory for later review.

[0044] FIGS. **6**-**9** show example images generated by conventional techniques and the DAM filtering technique according to principles of the present disclosure. Images generated by the DAM filtering technique may be provided on a display of an ultrasound imaging system (e.g., display **38** in FIG. **1**). Images may also be stored to a computer readable medium and/or provided to another display (e.g., a personal computer for post-exam review). The examples described below are illustrative and should not be interpreted to limit the implementations or applications of the DAM filtering technique to the examples disclosed herein.

[0045] FIG. **6** shows images **600** of a simulated phantom containing a 40 mm-diameter anechoic cyst lesion. The images were simulated for a 64-element P4-2 phased array. All images are shown on a 60 dB dynamic range. Image **605** was generated using standard delay-and-sum (DAS) beamforming with rectangular RX apodization. Image **610** was obtained by applying the DAM technique. Image contrast enhancement is visible with speckle texture well-preserved. The image smoothing technique described in FIGS. **4**A and **4**B was not applied.

[0046] FIG. **7** shows images **700** of an apical 4-chamber view of a heart from a healthy volunteer. The data was acquired with an 80-element S5-1 probe. Image **705** was formed with conventional DAS beamforming with rectangular apodization. Image **710** was obtained by applying the DAM technique. Enhancement in image contrast is observed, but some tissue signals have been lost. Right: Image **715** was obtained with the image smoothing technique described in FIGS. **4**A and **4**B. The smoothness and the details in the original image have been restored while preserving the enhanced contrast provided by the DAM technique.

[0047] The DAM technique described herein may address not only off-axis clutter and acoustic reverberation clutter,

but also noise introduced by grating lobes. Thus, the DAM technique may be desirable for use in applications where under-sampling may occur, which can introduce and/or enhance grating lobes. For example, intravenous ultrasound (NUS) applications may suffer from under-sampling. Grating lobes may appear in the lumen of the vessel, especially when there are stent struts that are highly reflective.

[0048] FIG. **8** shows IVUS images **800** of a simulated phantom containing six point scatterers and background noise. Image **805** was formed with the DAS beamforming and standard apodization. Image **810** was obtained by applying the DAM technique. Image contrast is improved in image **810** compared to image **805** due to incoherent signal (e.g., sidelobes and/or noise) suppression.

[0049] FIG. **9** shows IVUS images **900** of a stent. Image **905** was formed with conventional DAS beamforming. Image **910** was obtained by applying the DAM technique without image smoothing. Enhancement in image contrast is observed throughout image **910**. However, in this example, some grating artifacts inside the lumen add coherently, and therefore were not fully removed by the DAM technique.

[0050] According to principles of the disclosure, a DAM filtering technique as described herein may be applied to ultrasound channel data to suppress signals from off-axis sidelobes and/or clutter which may enhance image contrast. This may improve a clinician's ability to locate, recognize, and/or measure anatomical features in the image. The improved contrast may improve a clinician's ability to make diagnoses based on the ultrasound image. The DAM filtering technique may be easier to implement from a hardware perspective than some techniques that require access to per-channel data and/or may be less computationally intensive than some dual apodization techniques.

[0051] In various embodiments where components, systems and/or methods are implemented using a programmable device, such as a computer-based system or programmable logic, it should be appreciated that the above-described systems and methods can be implemented using any of various known or later developed programming languages, such as "C", "C++", "FORTRAN", "Pascal", "VHDL" and the like. Accordingly, various storage media, such as magnetic computer disks, optical disks, electronic memories and the like, can be prepared that can contain information that can direct a device, such as a computer, to implement the above-described systems and/or methods. Once an appropriate device has access to the information and programs contained on the storage media, the storage media can provide the information and programs to the device, thus enabling the device to perform functions of the systems and/or methods described herein. For example, if a computer disk containing appropriate materials, such as a source file, an object file, an executable file or the like, were provided to a computer, the computer could receive the information, appropriately configure itself and perform the functions of the various systems and methods outlined in the diagrams and flowcharts above to implement the various functions. That is, the computer could receive various portions of information from the disk relating to different elements ofthe above-described systems and/or methods, implement the individual systems and/or methods and coordinate the functions of the individual systems and/or methods described above.

[0052] In view of this disclosure it is noted that the various methods and devices described herein can be implemented in hardware, software and firmware. Further, the various methods and parameters are included by way of example only and not in any limiting sense. In view of this disclosure, those of ordinary skill in the art can implement the present teachings in determining their own techniques and needed equipment to affect these techniques, while remaining within the scope of the invention. The functionality of one or more of the processors described herein may be incorporated into a fewer number or a single processing unit (e.g., a CPU) and may be implemented using application specific integrated circuits (ASICs) or general purpose processing circuits which are programmed responsive to executable instruction to perform the functions described herein.

[0053] Although the present system has been described with reference to an ultrasound imaging system, the present system may be extended to other imaging techniques. Additionally, the present system may be used to obtain and/or record image information related to, but not limited to renal, testicular, prostate, breast, ovarian, uterine, thyroid, hepatic, lung, musculoskeletal, splenic, nervous, cardiac, arterial and vascular systems, as well as other imaging applications related to ultrasound-guided interventions and other interventions which may be guided by real-time medical imaging. Further, the present system may also include one or more elements which may be used with non-ultrasound imaging systems with or without real-time imaging components so that they may provide features and advantages of the present system.

[0054] Further, the present methods, systems, and apparatuses may be applied to existing imaging systems such as, for example, ultrasonic imaging systems. Suitable ultrasonic imaging systems may include a Philips® ultrasound system which may, for example, support a conventional broadband linear array transducer that may be suitable for small-parts imaging.

[0055] Certain additional advantages and features of this invention may be apparent to those skilled in the art upon studying the disclosure, or may be experienced by persons employing the novel system and method of the present invention, chief of which is reduction of noise from off-axis signals by ultrasound imaging systems and method of operation thereof is provided. Another advantage of the present systems and method is that conventional medical imaging systems may be easily upgraded to incorporate the features and advantages of the present systems, devices, and methods.

[0056] Of course, it is to be appreciated that any one of the above embodiments or processes may be combined with one or more other embodiments and/or processes or be separated and/or performed amongst separate devices or device portions in accordance with the present systems, devices and methods.

[0057] Finally, the above-discussion is intended to be merely illustrative of the present system and should not be construed as limiting the appended claims to any particular embodiment or group of embodiments. Thus, while the present system has been described in particular detail with reference to exemplary embodiments, it should also be appreciated that numerous modifications and alternative embodiments may be devised by those having ordinary skill in the art without departing from the broader and intended spirit and scope of the present system as set forth in the claims that follow. Accordingly, the specification and draw-

ings are to be regarded in an illustrative manner and are not intended to limit the scope of the appended claims.

What is claimed is:

1. A method comprising:

generating a first signal equivalent to summing aligned channel data with an apodization function with a first aperture applied, wherein the aligned channel data corresponds to ultrasound data;

generating a second signal equivalent to summing the aligned channel data with the apodization function with a second aperture applied, wherein the second aperture is complementary to the first aperture;

determining median values of the first signal, the second signal, and a third signal to generate a median value signal, wherein the third signal is constant value signal, wherein the constant value is zero or near zero; and

generating an ultrasound image, based at least in part, on the median value signal.

2. The method of claim **1**, wherein generating the second signal comprises:

summing the aligned channel data with a rectangular apodization function to generate a fourth signal; and

subtracting the first signal from the fourth signal to generate the second signal.

3. The method of claim **2**, further comprising applying bandpass filters to the first signal and the fourth signal prior to subtracting.

4. The method of claim **1**, further comprising scaling an amplitude of the median value signal.

5. The method of claim **1**, further comprising applying a bandpass filter to the median value signal.

6. The method of claim **1**, wherein generating the ultrasound image comprises applying envelope detection and log compression to the median value signal.

7. The method of claim **1**, further comprising:

generating an original image from the aligned channel data;

applying a first spatial low pass filter to the original image to generate a low frequency original image;

subtracting the low frequency original image from the original image to generate a high frequency original image;

applying a second spatial low pass filter to the ultrasound image to generate a low frequency ultrasound image; and

summing the high frequency original image and the low frequency ultrasound image to generate a final image.

8. The method of claim **1**, wherein the first aperture masks every other channel of the aligned channel data.

9. The method of claim **1**, wherein the first aperture masks multiple adjacent channels of the aligned channel data.

10. An ultrasound imaging system comprising:

an ultrasound transducer array configured to transmit and receive ultrasound signals;

a plurality of channels operatively coupled to the ultrasound transducer configured to transmit channel data based, at least in part, on the received ultrasound signals;

a beamformer operably coupled to the plurality of channels, the beamformer configured to align the channel data; and

a signal processor operatively coupled to the beamformer, wherein the signal processor is configured to:

receive aligned channel data from the beamformer;

generate a first signal equivalent to the aligned channel data summed with an apodization function with a first aperture applied;

generate a second signal equivalent to the aligned channel data summed with the apodization function with a second aperture applied, wherein the second aperture is complementary to the first aperture;

determine median values of the first signal, the second signal, and a third signal to generate a median value signal, wherein the third signal is a constant value signal, wherein the constant value is zero or near zero; and

generate an ultrasound image, based at least in part, on the median value signal.

11. The ultrasound imaging system of claim **10**, wherein the signal processor is further configured to apply a bandpass filter to the median value signal prior to generation of the ultrasound image.

12. The ultrasound imaging system of claim **10**, wherein the signal processor is configured to apply envelope detection and log compression to the median value signal to generate the ultrasound image.

13. The ultrasound imaging system of claim **10**, wherein the signal processor is further configured to:

generate an original image from the aligned channel data;

apply a first spatial low pass filter to the original image to generate a low frequency original image;

subtract the low frequency original image from the original image to generate a high frequency original image;

apply a second spatial low pass filter to the ultrasound image to generate a low frequency ultrasound image; and

sum the high frequency original image and the low frequency ultrasound image to generate a final image.

14. The ultrasound imaging system of claim **13**, wherein the original image is generated from a fourth signal generated by summing the aligned channel data with a rectangular apodization function.

15. The ultrasound imaging system of claim **13**, further comprising a display, wherein the display is configured to display at least one of the ultrasound image and the final image.

16. The ultrasound imaging system of claim **10**, further comprising a user interface.

17. The ultrasound imaging system of claim **16**, wherein a period of the first aperture is set by a user via the user interface.

18. The ultrasound imaging system of claim **16**, wherein the constant value is set by a user via the user interface.

19. The ultrasound imaging system of claim **10**, wherein the second signal is generated by:

summing the aligned channel data with a rectangular apodization function to generate a fourth signal; and

subtracting the first signal from the fourth signal to generate the second signal.

20. The ultrasound imaging system of claim **19**, wherein the signal processor is further configured to apply bandpass filters to the first signal and the fourth signal prior to subtraction.

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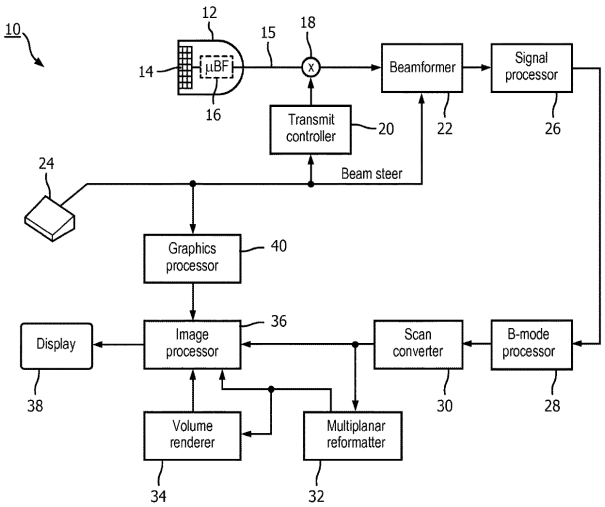
公开了用于抑制离轴旁瓣和/或杂波,近场混响杂波和/或光栅波瓣贡献的系统和方法。 公开了具有中值(DAM)滤波技术的双重变迹。 双重切趾技术可包括将具有应用的互补孔的切趾函数(406, 412, 414)的对齐通道数据求和。 确定零函数的中值(RF 3)和来自互补孔径的结果信号(RF 1,RF 2)以生成中值信号(416,)。 MVS)。 中值信号用于生成具有增强的图像对比度的超声图像。 还公开了一种具有增强的图像对比度的超声图像的图像平滑方法。 平滑的图像可以包括具有增强的图像对比度的超声图像的低频分量和原始图像的高频分量。