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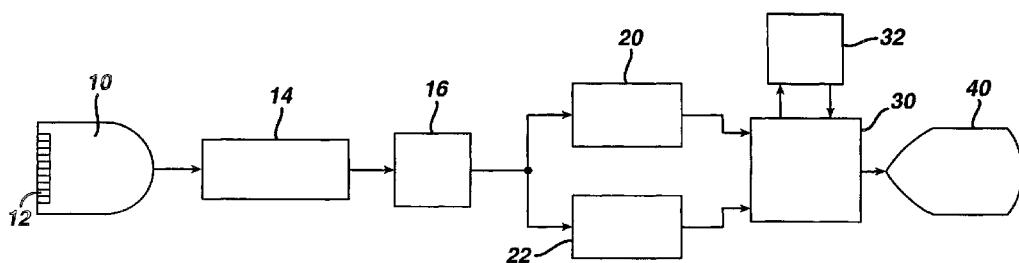
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(54) Title: ULTRASONIC DIAGNOSTIC IMAGE SYSTEM FOR LOW FLOW RATE CONTRAST AGENTS

**WO 03/104843 A1**

(57) Abstract: An ultrasonic diagnostic imaging system and method are presented to determine low rates of blood flow using contrast agents. Pairs of differently modulated pulses are transmitted in several beam directions to acquire echoes which can be combined to separate harmonic frequencies by pulse inversion. The pulses of each pair are transmitted in rapid succession to minimize motional artifacts. The transmission in the different beam directions is time-interleaved, resulting in the sampling of each beam direction over a long ensemble time for the detection of low rates of flow.

ULTRASONIC DIAGNOSTIC IMAGING SYSTEM
FOR LOW FLOW RATE CONTRAST AGENTS

5 This invention relates to ultrasonic diagnostic imaging systems and, in particular, to ultrasonic diagnostic imaging systems for detecting low velocity flow rates.

10 Ultrasonic contrast agents enable clinicians to image and quantify structures and functions in the body which are not otherwise readily seen or measured. The ability of ultrasonic contrast agents to resonate nonlinearly when excited with ultrasound can produce a strong harmonic response, enabling clear segmentation of vessels infused with the 15 contrast agent. A sharply defined image can be produced by disrupting the microbubbles of the contrast agent with high MI ultrasound as described in US patent 5,456,257. The ability to follow the progress of a contrast agent as it infuses the blood 20 vessels of tissue makes it possible to produce measures of myocardial perfusion using contrast, as described in US patent 5,833,613.

25 Recent studies of lesions such as breast lesions have focused on the vasculature of the lesion. Early detection of breast lesions and definition of the lesion boundaries can often be ascertained by using ultrasound to look for characteristic vascular structures. In addition, changes in lesion growth and development such as those resulting from 30 chemotherapy often manifest themselves at an early point in time by changes in the lesion vasculature. It is anticipated that these studies may be aided by the use of contrast agents. However, the vascular structures involved are tiny, micro-vascular 35 structures with individual vessels conducting minute

amounts of blood flow at very low rates of flow. It would be desirable to be able to use contrast enhanced ultrasound to detect the low rates of flow in such micro-vascular structures.

5 In accordance with the principles of the present invention, ultrasound is used to image micro-vascular structures with the aid of a contrast agent. Slow flow rates are discerned by time interleaving fast time ensembles among different beam directions, with
10 the response to each fast time ensemble used to detect the harmonic response by the pulse inversion technique. The aperiodic timing of an ensemble can be used to smooth undesired nulls in the Doppler spectrum.

15 In the drawings:

FIGURE 1 illustrates in block diagram form an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention;

20 FIGURE 2 illustrates details of the image processor of FIGURE 1;

25 FIGURE 3 illustrates a preferred embodiment of an image processor of an ultrasound system constructed in accordance with the principles of the present invention;

FIGURES 4a-4f illustrate the display of microbubbles flowing through micro-vascular structures in accordance with the principles of the present invention;

30 FIGURE 5 illustrates compound interleave pulse inversion sequences in accordance with the principles of the present invention; and

35 FIGURES 6a-6c illustrate Doppler filter characteristics which may be obtained through compound interleave pulse inversion in accordance

with the present invention.

In contrast-enhanced ultrasonic imaging with microbubble contrast agents, conditions sometimes exist in which the effective concentration of 5 microbubbles in tissue or blood is sufficiently low that individual microbubbles or clusters of microbubbles moving through a vessel appear as point targets in corresponding ultrasound images. The punctate appearance of the contrast agent in these 10 images can make it difficult to identify the architecture of blood vessels in the images. Improving the visibility of such blood vessels is of 15 clinical significance, since the morphology of blood vessels may be used for the detection and, in some cases, differentiation of suspicious lesions. The following apparatus and method improve the visibility of blood vessels and blood flow patterns by using temporal frame to frame processing of ultrasound contrast images.

20 Referring to FIGURE 1, an ultrasonic diagnostic imaging system constructed in accordance with the principles of the present invention is shown in block diagram form. A probe 10 includes an array transducer 12 which transmits ultrasound beams into a 25 subject and receives echoes from along the beam directions in response to the transmit beams, all under control of a beamformer 14. Echo signals produced by the beamformer are demodulated into quadrature I,Q components by a quadrature bandpass 30 (QBP) filter 16. Quadrature bandpass filters are well known in the art such as those described in US patent [application serial number 09/693,059], entitled "Ultrasonic Harmonic Flash Suppression." The echo samples are coupled to an echo processor 20 35 where the samples are processed for B mode display by

amplitude detection and log compression. The echo samples are also coupled to a flow processor 22 where they are used for Doppler estimation as described in US patents 5,386,830, 6,036,643, and 6,095,980. The 5 processed echo and flow signals are coupled to an image processor 30 where they are scan converted into the desired image format and displayed on a display 40 either separately or combined. A sequence of two dimensional images may be stored in an image buffer 10 32 where they may be replayed for more detailed study, or processed as by rendering to form a three dimensional image or image sequence.

The image processor 30 performs frame-to-frame image processing for contrast-enhanced ultrasound imaging. A first embodiment of the image processor 15 30 is shown in FIGURE 2. The image processor includes a scan converter 34 which converts received contrast signals into a desired display format, such as a rectangular or sector-shaped image. The scan converted images are then filtered by an inter-frame 20 high pass filter 36. The inter-frame high pass filter 36 is a temporal filter that may take the form of an FIR filter, an IIR filter or a frame-to-frame differentiator which filters successive images on a 25 pixel-by-pixel basis. Spatially corresponding pixels which are the same from frame to frame, such as pixels of stationary tissue, will produce a low- or zero-level output. Pixels which differ from frame to frame, as will occur when a microbubble moves into a 30 pixel location or out of a pixel location from frame to frame, will produce a finite output level for display. The inter-frame high pass filter 36 thus reduces signals from stationary and quasi-stationary 35 objects such as tissue and produces display level signals from moving microbubbles in the vasculature.

The high pass filtered contrast agent signals are applied to a persistence processor 38 which sustains a temporal sequence of detected microbubbles in the image. The persistence processor can have a 5 time constant for the persistence of a displayed microbubble which is greater than zero and as great as one. As the individual microbubble detection events build up (persist) in the image over time, the morphology of the tiny blood vessels through which 10 they are passing becomes visible. The persistence processor 38 can be operated with a high time constant, showing the continual passage of microbubbles through blood vessels and a continual buildup of the flow structure on the screen. The 15 persistence processor can also be given a lower time constant so that microbubble events will slowly decay away with time. Preferably the user is given a reset control 39 to reset the persistence to black at the start of an acquisition sequence or after a high time 20 constant sequence has filled the screen with microbubble events. It may further be desirable to combine the transmission of a high MI transmit frame with the reset control 39, causing the reset of the persistence processor to coincide with a high energy 25 frame which strongly disrupts the microbubbles currently in the image region.

A preferred persistence processor operates in accordance with:

$$30 \quad \text{OutputPixel}(x,y,k) = \max \{ \text{abs}[\text{InputPixel}(x,y,k)], P * \text{OutputPixel}(x,y,k-1) \}$$

where the time constant P has a range of $0 < P \leq 1$. When the time constant P is less than one, the trail of 35 displayed microbubble events will exhibit a fast attack, slow decay brightness that will start as a

bright event, then fade to black over time. When the time constant P is equal to one, the persistence processor will perform a maximum intensity projection of the current (k) and previous ($k-1$) pixel
5 brightnesses.

While the apparatus and method described above can be used when detecting contrast agents in the fundamental mode, it is preferable to carry out the inventive technique in the harmonic mode, to take
10 advantage of the strong segmentation and clutter rejection benefits of harmonic contrast operation. While a radiofrequency high pass filter can be used to pass the harmonic echo components in preference to the fundamental components, a preferred way to
15 separate the harmonic echo components of the contrast signal is by pulse inversion as described in US patent 5,706,819. As is well known, the pulse inversion technique involves the transmission of two or more transmit events of differently modulated
20 (phase or polarity or amplitude) transmit pulses along the same beam direction. Echoes received in response to the two transmit events are combined on a spatial basis. Opposite (inverse) phase or amplitude modulation of the transmit pulses will cause
25 fundamental signals of the two events to cancel, while nonlinear (harmonic) components will reinforce each other and thus be separated from the fundamental. The term "pulse" as used in pulse inversion generally refers to the complete transmit-
30 receive cycle of each differently modulated transmit pulse. Thus, two-pulse pulse inversion refers to the transmission of two differently modulated pulses, the reception of echo sequences following each transmit pulse or wave, and the combining of the two echo
35 sequence on a spatial (depth) basis. Pulse inversion

of more than two pulses may be employed with the present invention as described in US patent 6,186,950. Pulse inversion may also be performed by transmitting differently modulated pulses in adjacent beam directions, then separating the harmonic components by interpolation between beam locations as described in US patent 6,193,662.

In the embodiment of FIGURES 1 and 2, pulse inversion harmonic separation is performed prior to scan conversion by the scan converter 34. A convenient implementation is to use a line buffer following the beamformer 14 in which the echo sequence from one pulse is stored while a second, differently modulated echo sequence is acquired. The two sequences are combined to attenuate the fundamental components and accentuate the harmonic components of the contrast echo signals. The harmonic contrast echoes are filtered by the QBP filter 16 and processed by the echo processor 20. The echo data is scan converted and the image frames are temporally high pass filtered and persistence processed for display as described above.

The ability of a constructed embodiment of the present invention to depict blood vessel morphology is illustrated by the exemplary image sequence of FIGURES 4a-4f. These depict images of a real time image sequence that may develop over the time period of one to three heart cycles, for instance. In an early image in the sequence shown in FIGURE 4a, some clutter is seen in the near field in the 0-1 cm range, and five microbubbles are seen in the 1-3 cm range. The five microbubbles are depicted because they appeared in different locations in consecutive frames, causing frame-to-frame subtraction (temporal high pass filtering) to produce finite display

signals from the moving microbubbles. Signals from stationary tissues in consecutive frames, either fundamental (linear) or harmonic (nonlinear), will appear in the same location from frame to frame, and will be suppressed by the temporal high pass filter. Thus, clutter due to fundamental signal scattering will be reduced by the use of harmonic signals, and stationary tissue clutter will be diminished by the temporal high pass filter, thereby enabling the moving microbubbles to be distinguished in the image.

At a later time the image of FIGURE 4b is produced. This image shows the five microbubble events which were earlier seen in FIGURE 4a due to persistence processing. This image also shows the five microbubbles at new, adjacent locations as the microbubbles move through the micro-vessels in which they are flowing. At a later time the image of FIGURE 4c is produced. This image shows the previous locations of the five microbubbles by reason of persistence, and updated locations of the five microbubbles identified by temporal filtering. In this image, and in the later images of FIGURES 4d, 4e, and 4f, the tracks produced by the persisted, successive microbubble locations are seen to delineate the tortuous paths of the small blood vessels in which they are flowing. In addition, other tracks begin to appear as the contrast agent begins to reach other blood vessels in the image plane and begins to define their flow paths. FIGURE 4f would inform the clinician that six small vessels are located in the 1-3 cm range of the imaged sector, which may lead to the diagnosis of the presence of a lesion. It is possible that the track of six successive microbubble positions, as seen at 72 and 74 in FIGURE 4f, could be caused by six adjacent

vessels which are orthogonal to the image plane, but this is unlikely with longer tracks. The clinician can test this hypothesis by moving the probe slightly and reacquiring the microbubbles to test for a vessel 5 in the image plane.

If a time constant of $P=1$ is used, the sequence of images will contain an ever-increasing buildup of microbubble tracks until the region of the tracks is virtually all white. The persistence processor can 10 then be reset by the clinician and another sequence acquired. Alternatively, a lower value of $P<1$ can be used, and the older spots in the microbubble track 15 will fade away with time, enabling the image region to be observed for a considerable period of time before needing to be reset.

It is desirable to conduct microbubble tracking as described above at relatively low transmit power levels (low MI) so that the microbubbles will not be destroyed by the ultrasonic energy but will survive 20 over a period of many frames and be detected as they move through the micro-vasculature. However, it has been found that the procedure is effective even when there is some disruption of the microbubbles in the 25 vessels by the transmit energy, as usually a sufficient presence of microbubbles will survive over a period of several heart cycles.

A preferred image processor is shown in block 30 diagram form in FIGURE 3. Because the embodiment of FIGURE 2 uses a temporal high pass filter, it will be sensitive to some degree to probe motion. One way to reduce unwanted effects from probe motion is by harmonic flash suppression, as described in the aforementioned US patent [application serial number 09/693,059]. Another approach, which may be used 35 separately or in conjunction with flash suppression,

is to perform image registration 35 prior to the inter-frame high pass filter 36, as shown in FIGURE 3. Gross image registration from frame to frame can reduce the blurring of tissue/transducer motion and 5 will lead to a more effective temporal filter. The post-HPF processor 37 can perform image processing tasks such as thresholding, noise reduction, or frame-to-frame speckle tracking. The post-persistence processor 42 may perform image processing 10 such as edge enhancement or segmentation/thresholding. The processed contrast image may be blended with a conventional 2D echo image. The contrast image may also be segmented and applied as a color overlay over the 2D echo image as indicated by the blend/overlay processor 44. Either may be done 15 with or without image registration, but if the contrast image is registered, it is desirable that the 2D image be registered also so that probe and tissue motion are equally diminished in both images.

20 The tracks of microbubbles produced by an embodiment of the present invention can be used to calculate the absolute velocity of blood flow through the micro-vasculature. The bubbles can be seen to move a finite amount between frames along the curved 25 paths of the micro-vasculature. Since the scale of the pixel density relative to the anatomy being displayed is known, the distance traveled by a microbubble over a period of frames can be measured 30 in an image. From the knowledge of the frame rate (in frames per second) and the distance a microbubble has moved, the absolute velocity of the flow through the micro-vasculature can be calculated.

35 Other temporal display techniques may also be used. The flow into a lesion often shows a clearly pulsatile characteristic as it builds up in the

lesion, eventually filling the lesion. Arteries will be filled early in the filling period, with the capillary bed being filled in the latter part of the filling period. Vessels appearing in the early stage of filling can be color coded differently than those filled in the latter stage, giving a visual distinction between arteries and the capillary bed.

In accordance with the principles of the present invention, slowly flowing contrast agents are detected by a compound interleave of pulse inversion pulse ensembles, providing clutter rejection with improved sensitivity to very low velocity blood flow at high acquisition frame rates. In conventional pulse inversion Doppler imaging, it is desirable to have a Doppler frequency filter with a wide stop band at the Nyquist frequency to attenuate tissue signals, which requires a high sampling frequency (PRF, or pulse repetition frequency) and a narrow stop band at DC to sharply attenuate signals from entirely stationary objects, which requires a long sampling time between the first and last PRI's (pulse repetition intervals). If a total of M pulses per line of sight (beam direction) are required, then $N \times M$ pulses must be transmitted, producing an effective Doppler sample frequency of PRF/N , a total dwell time per line of $N \times (M-1)/PRF$, and a frame interval proportional to $N \times M$.

In accordance with the principles of the present invention, compound interleaving of pulse inversion pulse sequences is used to produce filters with the desired characteristics in relatively short sampling times. This provides a highly sensitive imaging technique for detecting low flow rates using pulse inversion Doppler operating at high acquisition frame rates. One such pulse sequence is shown in FIGURE 5

for two lines of sight or beam directions. The numbers at the left are a numbered sequence of the pulse repetition intervals (PRIs) used. During the first two PRIs two differently modulated pulses are transmitted in the first line of sight. The different modulation, which could be amplitude, phase, or polarity, is indicated by the "+" and "-" signs adjacent to each PRI line. The echoes of these two pulses are spatially combined to separate the harmonic components. Preferably these two pulses are transmitted in rapid succession so as to reduce motional artifacts in the received echoes, which can result in incomplete fundamental component cancellation.

Another two pulse sequence is transmitted in the second line of sight during PRIs 3 and 4. These pulses are also differently modulated so that the harmonics of the received echoes can be separated by pulse inversion combining of the received echoes. If a third line of sight were used, the next two pulse transmission would be in the third line. After all of the lines of sight of the sequence have been interrogated by a pair of pulses, the transmitter returns to the first line of sight. In the illustration in which the sequence only uses two lines of sight, pulses are transmitted along the first line of sight in PRIs 5 and 6. As the drawing indicates, both lines of sight are interrogated by rapid, two-pulse sequences in this time-interleaved manner until the full ensemble length has been completed, which in the illustration is three pulse-pairs in length. Each line of sight in this example is sampled by a plurality of fast PRF, two-pulse ensembles which together comprise a slow PRF ensemble length of three.

5 The resulting samples are used in a Doppler filter such as a matrix wall filter. Separate filters can be used for the fast PRF and slow PRF filters, or the two can be combined in a single filter. Suitable separate filter coefficients are:

2 -1 -1

Fast time filter = [.5 .5], Slow time filter = -1 2 -1
-1 -1 2

10

15 The first filter has a frequency response which attenuates fundamental tissue signals at the Nyquist limits of the sampling rate as shown by the Doppler filter response characteristic 60 in FIGURE 6a. The slow time filter will provide a sharp attenuation to this characteristic at DC as shown by the Doppler filter response 62 in FIGURE 6b, which attenuates nonlinear signals from stationary microbubbles and tissue harmonics. Slow moving contrast, which will 20 have a Doppler frequency in the vicinity of zero, will be passed on either side of this central null.

25 The frequency response characteristic for this example also is seen to exhibit two other intermediate nulls about halfway between DC and the Nyquist limits of ± 0.25 PRF. These nulls are not likely to affect the result obtained from very slow rates of flow, but can come into play and cause signal drop-out during high flow conditions. In accordance with a further aspect of the present 30 invention, these intermediate nulls are diminished by using aperiodic time-interleaved sequences. The slow time ensemble is made aperiodic by varying the timing of one or more of the fast time ensembles. Another approach to aperiodic compounding is to vary the 35 interleave ratio over consecutive image frames. An

example of an aperiodic compound interleave sequence is:

	Line number	Temporal sequence of pulses
5	1	[1,1,0,0,0,0,1,1,0,0,1,1,0,0]
	2	[0,0,1,1,0,0,0,0,1,1,0,0,1,1]

where each "1" in the sequence indicates that a modulated pulse of some sort is transmitted and echoes received during the particular pulse repetition interval. In this example it is seen that a fast time sequence of two pulses is transmitted and received along line 1, followed by transmission and reception of a fast time sequence of two pulses along line 2. During the next two pulse intervals no pulses are transmitted along either line. Thereafter fast time sequences of two pulses are alternately transmitted along the two lines. The aperiodicity of the slow time ensembles caused by skipping transmission of the normally recurring second fast time ensemble in PRIs 5 and 6 (for line 1) and PRIs 7 and 8 (for line 2) causes the frequency response of the filter to be rippled without sharp intermediate nulls, as shown in FIGURE 6c, a result which is also aided by expected spectral broadening.

The aperiodic interleaving of fast time sequences can be extended to conventional Doppler operating in the fundamental mode with or without contrast agents. Aperiodic interleave and sampling make it possible to generate a Doppler wall filter using very few samples that mimics the performance of wall filters generated with much longer ensemble lengths. For example, consider the following interleave of four pulses over three lines:

Line number	Temporal sequence of pulses
1	[1,0,0,0,0,1,0,0,1,0,0,0,0,1,0,0]
2	[0,1,0,0,0,0,1,0,0,1,0,0,0,0,1,0]
3	[0,0,1,0,0,0,0,1,0,0,1,0,0,0,0,1]

5 A wall filter using samples from this aperiodic ensemble will have low frequency performance similar to an ensemble length of 14, (the PRI duration from the first to the last sample along each line) but with only four samples per filter. Preferably the 10 velocity estimation algorithm used will be modified in consideration of the aperiodicity of the sampling.

15 The use of aperiodic slow time ensembles may find particular utility in real time three dimensional imaging. In real time 3D it is desirable to be able to scan the entire volumetric region in as short a time as possible, to obtain a high frame rate of display. For Doppler imaging in 3D, a high aliasing cutoff frequency and long (in time) slow time ensembles are desirable in order to detect both 20 high and low flow rates. Traditionally these demands are satisfied by transmitting a long sequence of high PRF pulses down each line, causing long acquisition times and slow frame rates. A time interleaved, aperiodic scan such as that shown above will 25 interrogate each line over a long period of time from the first pulse interval to the last pulse interval, thereby providing good low flow rate sensitivity. The aperiodic timing between consecutive acquisitions along each line provides a high effective aliasing 30 (Nyquist) frequency. Since only a few pulses are needed for each line, many lines can be time interleaved at the cost of only a reduction in the signal to noise ratio of the resultant Doppler estimates.

35 Embodiments of the present invention can operate

on either demodulated echo samples or r.f. data. The fast time ensembles can be more than two pulses in length, such as the three, four, and five pulse ensembles for pulse inversion described in the 5 aforementioned US patent 6,186,950.

WHAT IS CLAIMED IS:

1. A method for detecting low velocity motion of a substance which returns ultrasonic harmonic echo signals comprising:

transmitting a first fast time ensemble of a plurality of pulses in a first direction;

transmitting a third fast time ensemble of a plurality of pulses in the first direction; and

10 prior to transmitting the third fast time ensemble, transmitting a second fast time ensemble in a second direction,

15 wherein the first and third fast time ensembles comprise a slow time ensemble transmitted in the first direction.

2. The method of Claim 1, wherein transmitting further comprises receiving echoes in response to the transmission of each pulse in a given direction.

20 3. The method of Claim 2, further comprising separating harmonic echo components by pulse inversion processing of the echoes of each fast time ensemble.

25 4. The method of Claim 3, wherein the number of pulses of a fast time ensemble is two.

30 5. The method of Claim 3, wherein the number of pulses of a fast time ensemble is greater than two.

6. The method of Claim 3, further comprising Doppler processing the separated harmonic echo components of a slow time ensemble.

7. The method of Claim 6, wherein separating harmonic echo components by pulse inversion processing comprises attenuating the contributions of fundamental frequency echoes; and

5 wherein Doppler processing the separated harmonic echo components comprises detecting low rates of blood flow.

10 8. The method of Claim 7, wherein Doppler processing the separated harmonic echo components further comprises attenuating the contributions of harmonic echo components from stationary objects.

15 9. The method of Claim 1, wherein transmitting a fast time ensemble comprises transmitting at least two pulses which are differently modulated in at least one of phase, polarity, or amplitude.

20 10. A method for producing ultrasonic Doppler ensembles of harmonic signals comprising:

selecting a plurality of beam directions which are to be sampled in a time-interleaved group;

transmitting a first plurality of fast time pulses in the direction of a first one of the beams;

25 transmitting a first plurality of fast time pulses in the directions of all of the other beams in the group before transmitting again in the first beam direction;

30 transmitting a second plurality of fast time pulses in the direction of the first one of the beams; and

35 transmitting a second plurality of fast time pulses in the directions of all of the other beams in the group before transmitting again in the first beam direction.

11. The method of Claim 10, wherein
transmitting a plurality of fast time pulses further
comprises receiving echoes in which harmonic
5 components are to be identified by pulse inversion
processing.

12. The method of Claim 11, further comprising
Doppler processing an ensemble of harmonic echo
10 components in each beam direction to detect low rates
of flow.

13. The method of Claim 10, wherein
transmitting a plurality of fast time pulses
15 comprises transmitting fast time pulses in each beam
direction at regularly recurring intervals.

14. The method of Claim 10, wherein
transmitting a plurality of fast time pulses
20 comprises transmitting fast time pulses in each beam
direction at aperiodic intervals.

15. The method of Claim 10, wherein
transmitting a plurality of fast time pulses
25 comprises transmitting at least two pulses which are
differently modulated in at least one of phase,
polarity, or amplitude.

16. An ultrasonic diagnostic imaging system
30 comprising:

an array transducer (12) which acts to transmit
and receive in selectable beam directions;
a beamformer (14), coupled to the array
transducer (12), which acts to transmit groups of two
35 or more pulses in each beam direction in rapid

succession, the transmit groups being time-interleaved over a plurality of beam directions; a Doppler processor, coupled to the beamformer (14), which processes harmonic components from low flow rate substances which have been separated by the 5 pulse inversion process.

17. The ultrasonic diagnostic imaging system of Claim 16, wherein the pulses of the transmitted 10 groups of two or more pulses are differently modulated.

18. The ultrasonic diagnostic imaging system of Claim 17, wherein the pulses of the transmitted 15 groups of two or more pulses are differently modulated in at least one of phase, polarity, or amplitude.

19. A method for ultrasonically estimating the 20 flow rate of slowly moving materials comprising:

- a) selecting a plurality of beam directions which are to be sampled in a time-interleaved manner;
- b) transmitting in rapid succession in a first beam direction two pulses of a given frequency which are differently modulated in at least one of phase, 25 polarity, or amplitude, and receiving echoes following each pulse;
- c) repeating step b) in at least a second beam direction;
- d) following step c), repeating step b) at least one further time in the first beam direction;
- e) following step d), repeating step c) at least one further time; and
- f) processing the echoes received in each beam 35 direction to detect flow at spatial locations in each

beam direction.

20. The method of Claim 19, wherein processing further comprises combining the echoes from each 5 pulse pair to distinguish harmonic echo components.

21. The method of Claim 20, wherein processing further comprises Doppler processing the echoes received in each beam direction as an ensemble of 10 samples spanning the time intervals from step b) through step d) or from step c) through step e).

22. The method of Claim 21, wherein Doppler processing comprises wall filtering an ensemble of 15 samples in each beam direction.

23. A method for acquiring an ensemble of signal samples for Doppler processing comprising: transmitting pulses sequentially in a plurality 20 of beam directions in an interleaved manner and acquiring echoes along a beam direction following each pulse; and

25 acquiring an ensemble of echoes for each beam direction, wherein the intervals between the transmit pulses of an ensemble are not all identical.

24. The method of Claim 23, wherein transmitting comprises transmitting pulses sequentially in a plurality of beam directions in a 30 volumetric region in an interleaved manner and acquiring echoes along a beam direction following each pulse.

25. The method of Claim 23, further comprising 35 Doppler processing the acquired echoes for each beam

direction.

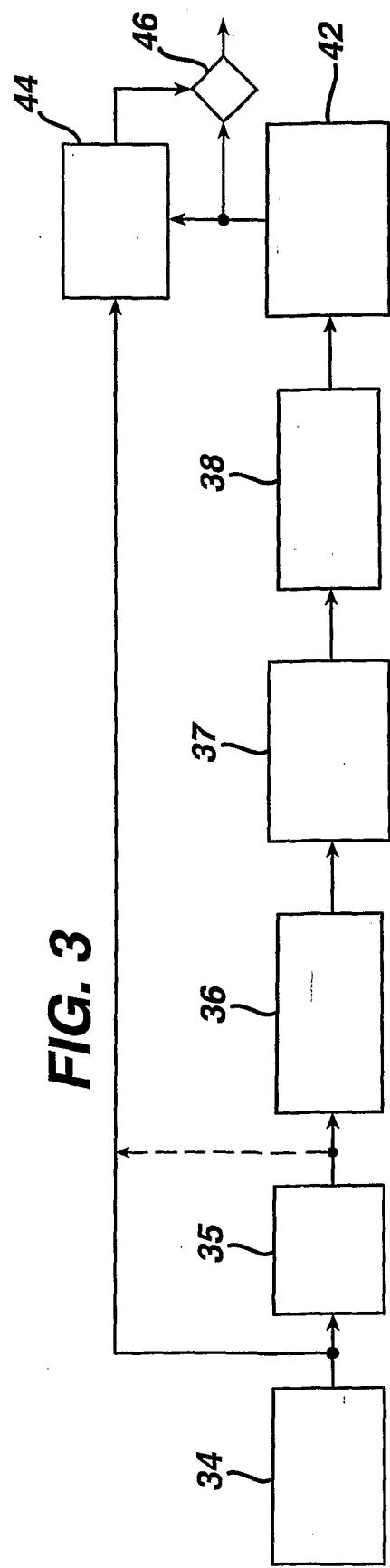
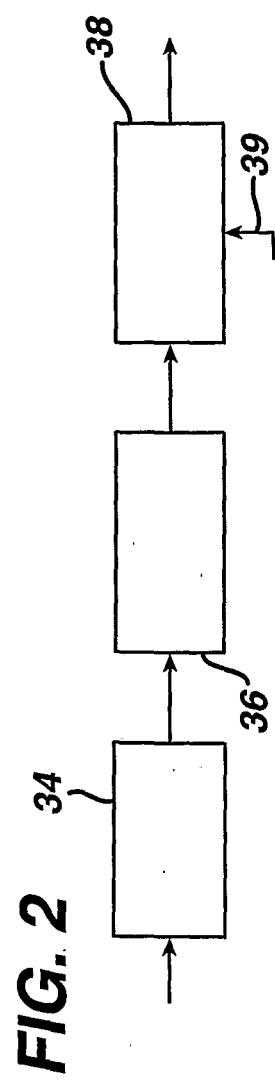
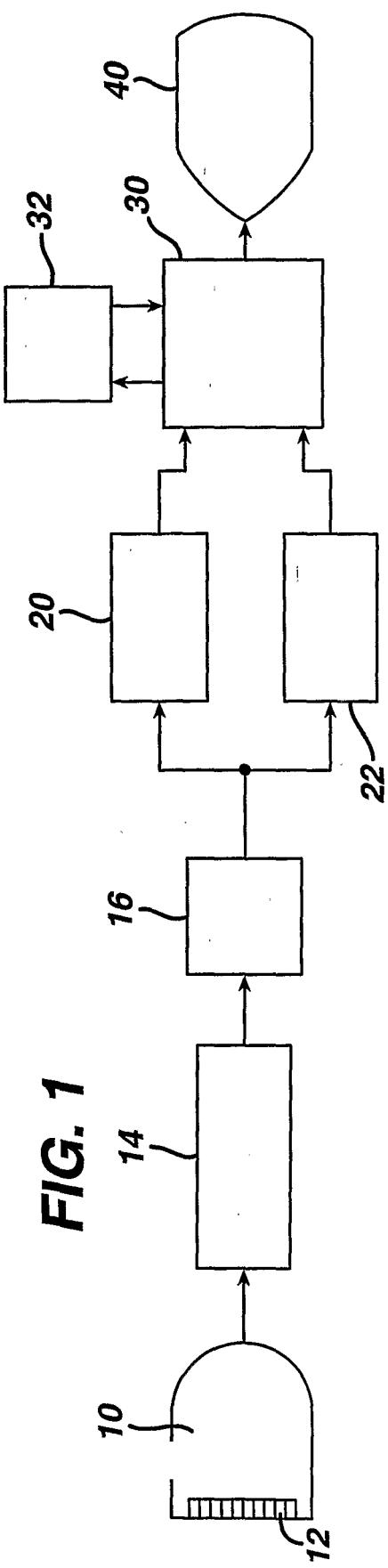


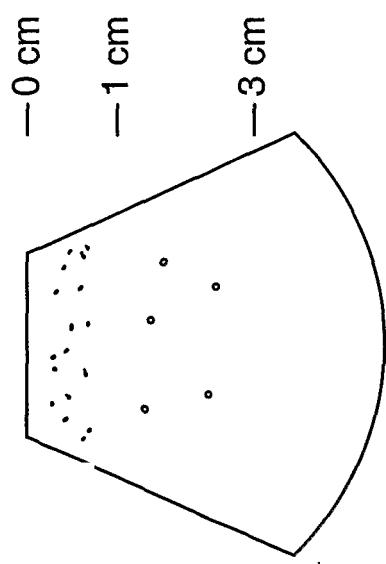
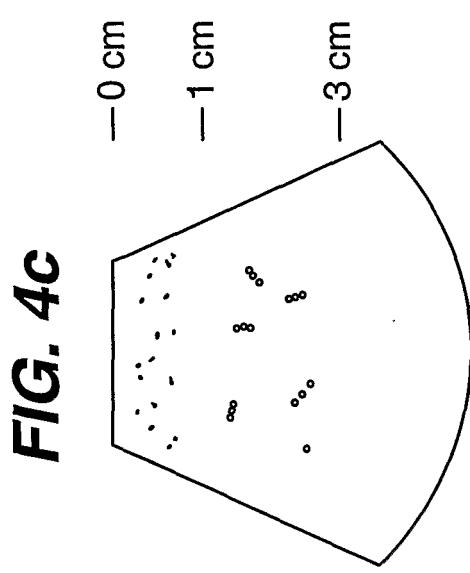
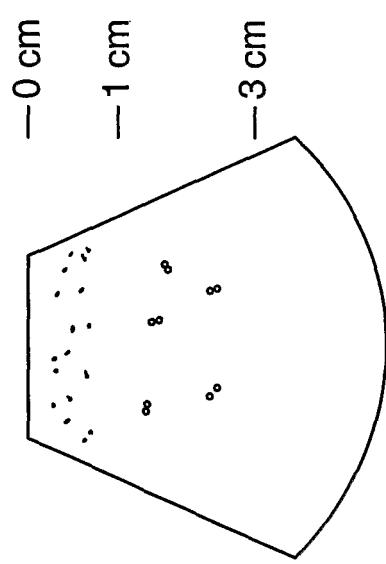
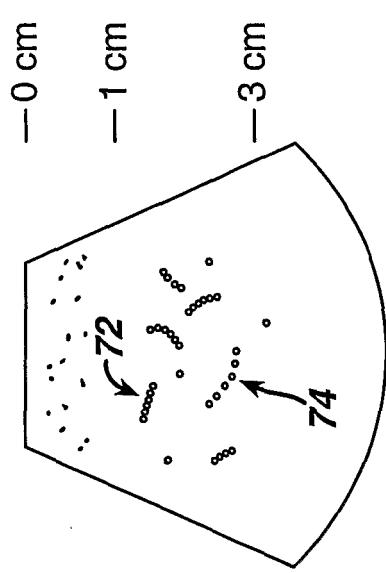
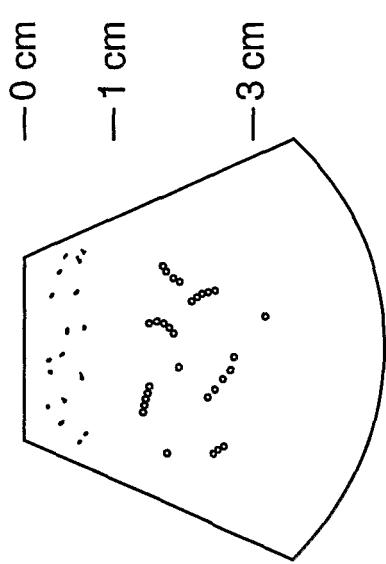
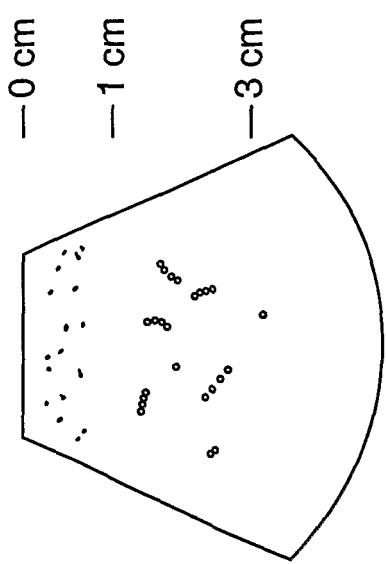
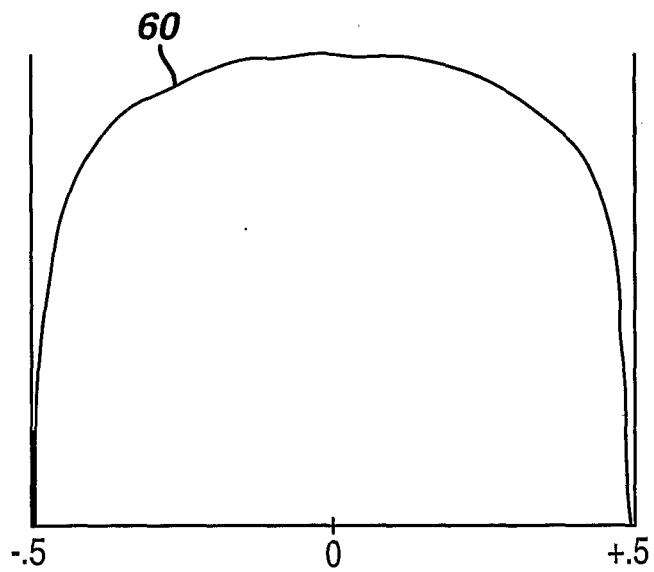
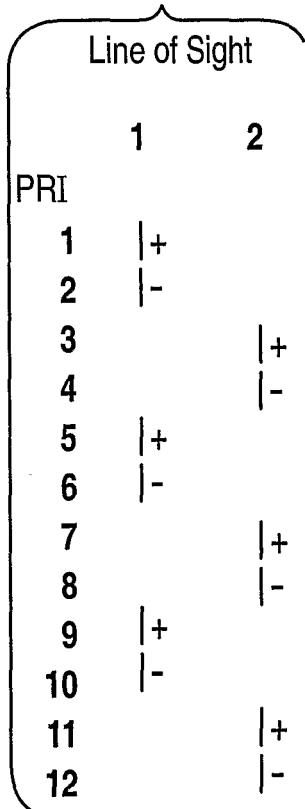
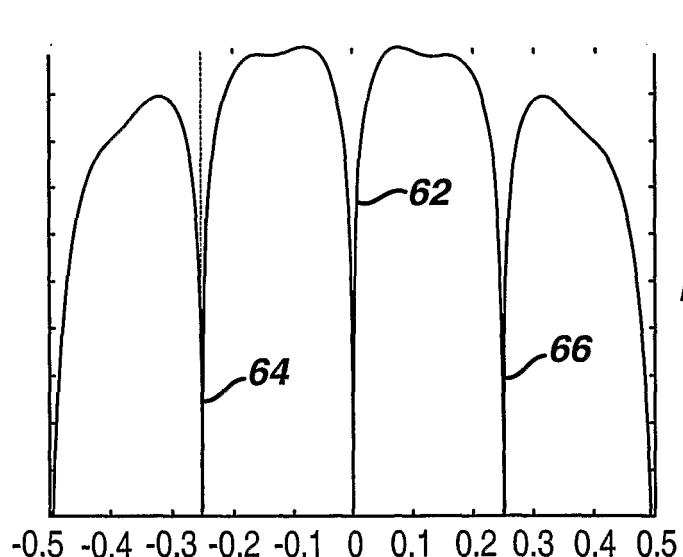
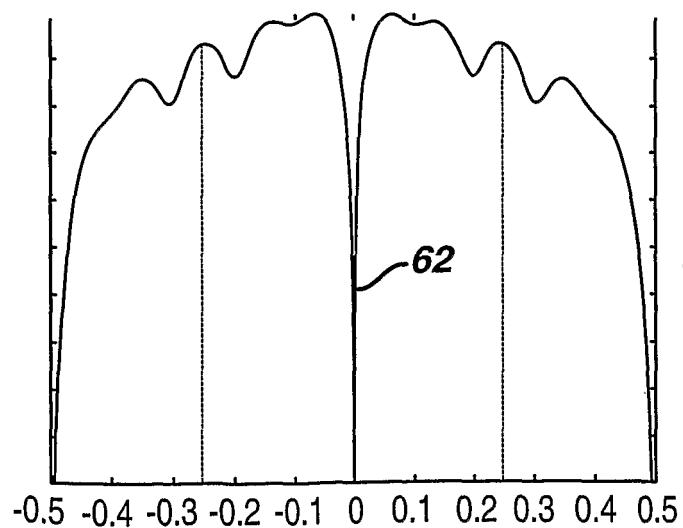
FIG. 4a**FIG. 4b****FIG. 4c****FIG. 4f****FIG. 4e****FIG. 4d**

FIG. 5**FIG. 6a****FIG. 6b****FIG. 6c**

INTERNATIONAL SEARCH REPORT

International Application No

PCT/IB 03/02095

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01S15/89

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01S

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

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

EPO-Internal, WPI Data, COMPENDEX, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 186 950 B1 (AVERKIOU MICHALAKIS ET AL) 13 February 2001 (2001-02-13) abstract; figure 10 column 7, line 6 - line 32 ---	1,10,16, 19,23
A	US 2001/039381 A1 (BURNS PETER N ET AL) 8 November 2001 (2001-11-08) paragraph '0060! ---	1,10,16, 19,23
A	WO 01 64108 A (ACUSON) 7 September 2001 (2001-09-07) abstract; claims 15,30,31 page 14, line 3 - line 26 ---	1,10,16, 19,23

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

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- *&* document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 September 2003	24/09/2003
Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Niemeijer, R

INTERNATIONAL SEARCH REPORT

International Application No

PCT/IB 03/02095

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 095 980 A (BURNS PETER N ET AL) 1 August 2000 (2000-08-01) abstract; figures 2,3 column 4, line 34 - line 45 column 5, line 29 - line 61 -----	1,10,16, 19,23

INTERNATIONAL SEARCH REPORT

International Application No

PCT/IB 03/02095

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
US 6186950	B1	13-02-2001	WO EP JP	0133250 A1 1145042 A1 2003512914 T		10-05-2001 17-10-2001 08-04-2003
US 2001039381	A1	08-11-2001		NONE		
WO 0164108	A	07-09-2001	US AU DE WO	6494841 B1 3501801 A 10195815 T0 0164108 A1		17-12-2002 12-09-2001 12-06-2003 07-09-2001
US 6095980	A	01-08-2000	EP JP NO	0913704 A2 11178824 A 984604 A		06-05-1999 06-07-1999 06-04-1999

专利名称(译)	用于低流速造影剂的超声诊断图像系统		
公开(公告)号	EP1516204A1	公开(公告)日	2005-03-23
申请号	EP2003727779	申请日	2003-05-16
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
当前申请(专利权)人(译)	皇家飞利浦电子N.V.		
[标]发明人	BRUCE MATTHEW HOPE SIMPSON DAVID		
发明人	BRUCE, MATTHEW HOPE SIMPSON, DAVID		
IPC分类号	A61B8/06 G01S7/52 G01S15/89		
CPC分类号	G01S15/8963 G01S7/52038 G01S7/52039 G01S7/52085 G01S15/8981		
优先权	10/170153 2002-06-11 US		
外部链接	Espacenet		

摘要(译)

提出了一种超声诊断成像系统和方法，以使用造影剂确定低血流速率。在几个波束方向上发送成对的不同调制脉冲以获取回波，该回波可以通过脉冲反转被组合以分离谐波频率。每对脉冲快速连续传输，以最小化运动伪影。不同波束方向上的传输是时间交织的，导致在长的整体时间内对每个波束方向进行采样，以检测低流速。