

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
3 November 2005 (03.11.2005)

PCT

(10) International Publication Number
WO 2005/103758 A1

(51) International Patent Classification⁷: G01S 15/89, 7/52

(21) International Application Number:
PCT/IB2005/051238

(22) International Filing Date: 15 April 2005 (15.04.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/563,608 20 April 2004 (20.04.2004) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

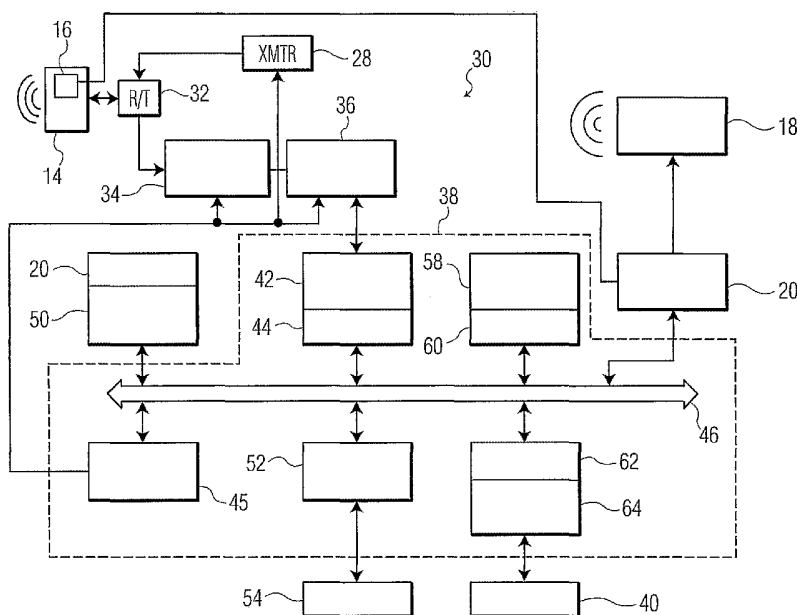
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA,

[Continued on next page]

(54) Title: MULTIZONE COLOR DOPPLER BEAM TRANSMISSION METHOD



(57) Abstract: A method is disclosed herein for producing color Doppler images of a subject. The method comprises the steps of transmitting (401) first and second transmit beams into the subject, wherein said first and second transmit beams are characterized by first and second frequencies, and wherein each of said first and second transmit beams has first and second sets of receive beams associated therewith, respectively; receiving (403) the first and second sets of receive beams; and producing (405) a composite color Doppler image based on the first and second sets of receive beams.

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CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR,

HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)

- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations

Published:

- with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

MULTIZONE COLOR DOPPLER BEAM TRANSMISSION METHOD

The present invention relates generally to ultrasound imaging, and more particularly to methods for improving near field resolution and far field sensitivity in color Doppler imaging.

5 Conventional sonography is conducted with the use of diagnostic ultrasound equipment that transmits sound energy into the human body and receives the signals that reflect off of bodily tissues and organs such as the heart, liver, and kidneys. Blood flow patterns may be obtained from Doppler shifts or from shifts in time domain cross correlation functions due to blood cell motion. These shifts produce reflected sound waves
10 that may be generally displayed in a two-dimensional format known as color flow imaging or color velocity imaging. A typical ultrasound system emits pulses over a plurality of paths and converts echoes received from objects on the plurality of paths into electrical signals used to generate ultrasound data from which an ultrasound image can be displayed. The process of obtaining the raw data from which the ultrasound data is produced is
15 typically termed "scanning," "sweeping," or "steering a beam".

Sonography may be performed in real time, which refers to the presentation of ultrasound images in a rapid sequential format as the scanning is being performed. Typically, the scanning that gives rise to the image is performed electronically, and utilizes a group of transducer elements (called an "array") which are arranged in a line and
20 which are excited by a set of electrical pulses, one pulse per element. The pulses are typically timed to construct a sweeping action.

Signal processing in an ultrasound scanner usually begins with the shaping and delaying of the excitation pulses applied to each element of the array so as to generate a focused, steered and apodized pulsed wave that propagates into the tissue. The
25 characteristics of the transmitted acoustic pulse may be adjusted or "shaped" to correspond to the setting of a particular imaging mode. For example, pulse shaping may include adjusting the length of the pulse for different lines depending on whether the returned echoes are ultimately to be used in B-scan, pulsed Doppler or color Doppler imaging modes. Pulse shaping may also include adjustments to the central frequency which, in
30 modern broadband transducers, can be set over a wide range and may be selected according to the part of the body that is being scanned. A number of scanners also shape

the envelope of the pulse (i.e., by making it Gaussian in shape) to improve the propagation characteristics of the resulting sound wave.

Echoes resulting from scattering of the sound by tissue structures are received by all of the elements within the transducer array and are subsequently processed. The
5 processing of these echo signals typically begins at the individual channel or element level with the application of apodization functions, dynamic focusing, steering delays, and other such procedures.

One of the most important elements in signal processing is beam forming. In a transducer array, the beam is focused and steered by exciting each of the transducer
10 elements at a different time so that the resulting sound wave coming from each element will arrive at the intended focal point simultaneously.

This principle may be understood in reference to **FIGURE 1**, which depicts a transducer array **101** having transducers **103**, **105**, **107** and **109** that are at distances d_1 , d_2 ,
15 d_3 and d_4 , respectively, from focal point **111**. In the case depicted, the beam is being focused and steered to the left. Since the distance d_1 from the focal point to transducer element **103** of the transducer array is shorter than the distance d_4 from the focal point to transducer element **109**, during transmission, element **109** must be excited before elements
20 **103**, **105**, and **107** in order for the waves generated by each element to arrive at the focal point simultaneously. By contrast, in the case shown in **FIGURE 2**, the focal point **113** is to the right. Here, the elements of the transducer must be excited in the reverse order during transmission (that is, element **103** must be excited before elements **105**, **107**, and **109**) in order for the waves generated by each element to arrive at the focal point simultaneously. This process of coordinating the firing of transducer elements is referred to as "beam formation", and the device which implements this process is called a "beam
25 former".

Beam forming is typically implemented during both transmission (described above) and reception. Beam forming on reception is conceptually similar to beam forming on transmission. On reception, an echo returning from a given point **111** (see **FIGURE 1**) encounters each of the elements **103**, **105**, **107** and **109** in the transducer array **101** at a
30 different time due to the varying distances d_1 , d_2 , d_3 and d_4 , respectively, of these elements from focal point **111**. Consequently, the signals coming into the ultrasound scanner from the various elements must be delayed so that they all "arrive" at the same moment. The

signals from each element are then summed together to form the ultrasound signal that is subsequently processed by the rest of the ultrasound instrument. Typically, 1-dimensional arrays having 32 to 192 transducer elements are used for beam formation. The signal from each individual element is delayed in order to steer the beam in the desired direction.

5 The beam former, in addition to combining the received signals into an output signal, also focuses the beam. When dynamic focusing is used, for each pulse which is transmitted from the array, the beam former tracks the depth and focuses the receive beam as the depth increases. The receive aperture will usually be allowed to increase with depth, since this achieves a lateral resolution which is constant with depth and decreases
10 sensitivity to aberrations in the imaged medium. In order for the receive aperture to increase with depth, it is necessary to dynamically control the number of elements in the array that are used to receive the echoes. Since often a weighting function (apodization) is used to reduce or eliminate side lobes from the combined signal, the element weights also have to be dynamically updated with depth.

15 Most ultrasound scanners are able to perform parallel beam forming. Parallel beam forming refers to the acquisition of multiple roundtrip beams from a single transmit event by focusing multiple receive beams within a single transmit beam. The transmit beam, due to its single focus, is typically apodized to improve depth of field and is therefore inherently wider than the dynamically focused receive beams. The receive beams
20 have local acoustical maxima which are off-axis relative to the transmit beam. Parallel beam forming allows the imaged field to be scanned faster and thus allows the frames to be updated faster. Parallel beam forming is especially advantageous in 3-D imaging, due to the large number of frames that need to be gathered.

 While the use of beam formers and beam forming procedures has significantly
25 improved the quality of acoustical images, a number of challenges remain in the art. In particular, current acoustical imaging technology typically requires a tradeoff between near field resolution (usually provided by higher frequencies, and typically confined to the first centimeter or so of depth in the subject) and far field sensitivity (usually provided by lower frequencies). Consequently, for example, while significant improvements have been made
30 in resolution of low flow velocities, these improvements have typically come at the expense of depth of field. Some approaches utilize a frequency shift, so that near field scanning is conducted at a first frequency and far field scanning is conducted at a second

frequency. However, this approach is less than optimal and provides poor resolution of features that have significant depth of field. This type of approach also frequently produces imaging artifacts.

There is thus a need in the art for a method for improving the resolution of color Doppler imaging across the entire depth of the image. There is further a need in the art for a method for improving near field resolution and far field sensitivity in color Doppler imaging. These and other needs are met by the methodologies and devices disclosed herein and hereinafter described.

In one aspect, a method for producing color Doppler images of a subject is provided. The method comprises the steps of transmitting first and second transmit beams into the subject, wherein said first and second transmit beams are characterized by first and second frequencies, and wherein each of said first and second transmit beams has first and second sets of receive beams associated therewith, respectively; receiving the first and second sets of receive beams; and producing a composite color Doppler image based on the first and second sets of receive beams. The composite image may be derived from the weighted average of the first and second sets of receive beams, in which case the weighted average may be derived by applying first and second weighting factors to the first and second sets of receive beams, respectively. The first and second weighting factors may be chosen to optimize sensitivity and near field resolution.

Preferably, the first frequency is a high frequency and the second frequency is a low frequency. Even more preferably, the difference between the first and second frequencies is at least about 2 MHz, and most preferably, the difference between the first and second frequencies is within the range of about 2 MHz to about 7 MHz. Any number of additional transmit beams may be utilized that have frequencies between the frequencies of the first and second transmit beams.

The first and second frames may be derived from frequency estimates based on the first and second sets of receive beams. Put another way, the composite image, which is preferably a color Doppler image, may be derived from frequency estimates corresponding to the first and second sets of receive beams. The composite image may be formed by averaging the complex signal estimates used to produce the frequency estimate for the first set of receive beams with the complex signal estimates used to produce the frequency

estimate for the second set of receive beams. Thus, for example, the first (F_1) and second (F_2) frequencies may be such that $V_1 = V_2$, wherein

$$V_1 = PRF_1 \cdot c / (2F_1 \cos(\theta)) \text{ and}$$

$$V_2 = PRF_2 \cdot c / (2F_2 \cos(\theta)), \text{ and wherein:}$$

- 5 PRF_1 is the color Doppler pulse repetition frequency associated with F_1 ;
 PRF_2 is the color Doppler pulse repetition frequency associated with F_2 ;
 θ is the color Doppler angle (typically constant); and
 c is the speed of sound.

 In another aspect, a method for acoustically imaging a subject is provided which
10 comprises the steps of transmitting first and second transmit beams into the subject,
 wherein the first and second transmit beams are characterized by first and second
 frequencies F_1 and F_2 , respectively, wherein $F_1 > F_2$; receiving first and second sets of
 receive beams corresponding, respectively, to first and second transmit beams; determining
 the frequencies of the first and second sets of receive beams; applying first and second
15 weighting factors to the determined frequencies, thereby producing first and second
 weighted frequencies; and producing a composite color Doppler image based on the first
 and second weighted frequencies. Preferably, each of said first and second sets of receive
 beams has a plurality of members.

 In still another aspect, a method is provided for producing color Doppler images
20 of a subject. The method comprises the steps of obtaining a grey scale image frame from
 the subject; obtaining a first color image frame from the subject by transmitting a first
 transmit beam into the subject and receiving a first set of receive beams that are associated
 with the first transmit beam, wherein said first transmit beam is characterized by a first
 frequency and has a first set of receive beams associated therewith; obtaining a second
25 color image frame from the subject by transmitting a second transmit beam into the
 subject, wherein said second transmit beam is characterized by a second frequency and has
 a second set of receive beams associated therewith, wherein said second frequency is
 distinct from said first frequency; receiving the first and second sets of receive beams; and
 producing a composite color Doppler image based on the first and second sets of receive
30 beams.

 These and other aspects of the teachings herein are described in further detail
 below.

For a more complete understanding of the present invention and advantages thereof, reference is now made to the following description which is to be taken in conjunction with the accompanying drawings in which like reference numbers indicate like features and wherein:

5 **FIGURE 1** is a diagram illustrating the need for time delay to account for differences in the distances between the elements of a transducer array and a focal point in an ultrasound diagnostic system;

FIGURE 2 is a diagram illustrating the need for time delay to account for differences in the distances between the elements of a transducer array and a focal point in
10 an ultrasound diagnostic system;

FIGURE 3 is a flow chart illustrating the frame acquisition sequence in one embodiment of the methodology disclosed herein;

FIGURE 4 is a flow chart illustrating a system for implementing the methodology disclosed herein;

15 **FIGURE 5** is an illustration of a 4-way parallel beam pattern on the receive side;

FIGURE 6 is an illustration of an ultrasound device which may be used to implement the methodologies disclosed herein;

FIGURE 7 is a schematic diagram illustrating the functional elements of a
20 device of the type depicted in **FIGURE 6**; and

FIGURE 8 is a flow chart illustrating one embodiment of the methodology disclosed herein.

It has now been found that the aforementioned needs may be met by utilizing multiple transmit beams characterized by multiple transmit and/or receive frequencies.

25 Thus, in a preferred embodiment, first and second transmit beams are transmitted into the subject, wherein the first and second transmit beams are characterized by first and second frequencies, and wherein each of the first and second transmit beams has first and second sets of receive beams associated therewith, respectively. The first and second sets of receive beams are then received and utilized to produce a composite color Doppler image.
30 This approach improves the resolution of color Doppler imaging across the entire depth of the image, and allows near field resolution to be improved without adversely affecting far field sensitivity.

One preferred embodiment of the methodology disclosed herein may be understood generally with reference to **FIGURE 3**, which depicts a data acquisition sequence that could be utilized in forming a composite color Doppler image in accordance with the teachings herein. In the particular sequence **201** depicted therein, an echo frame is acquired **203**, followed by the acquisition of a high frequency color frame **205** (e.g., 9 MHz, utilized for the near field) and a low frequency (e.g., 6 MHz, utilized for the far field) color frame **207**. This sequence is then repeated for the remainder of the imaging process.

In alternative embodiments of this process, data acquisition may be conducted on a line-by-line basis rather than on a frame-by-frame basis. Thus, for example, in such embodiments, a line of the high frequency color frame could be gathered, followed by a line of the low frequency color frame, and this process could be repeated until an entire frame is collected. Such alternative embodiments may be undesirable in applications where substantial amounts of decaying echoes will be present that would tend to interfere with the data acquisition process.

In still other embodiments, multiple frames may be acquired at a given frequency followed by the acquisition of frames at another frequency. For example, multiple frames could be acquired at a high frequency, each frame being acquired at a different depth, followed by the acquisition of multiple frames at a lower frequency (again, each frame being acquired at a different depth).

Alternatively, the sequence shown in **FIGURE 3** could be utilized, but the focus depth of one or both of the frequencies utilized could change from one iteration to the next. For example, one iteration could be implemented with the high frequency (9 MHz) beam focused at 1 cm and the low frequency (6 MHz) beam focused at 4 cm, followed by the associated echo frames. A subsequent iteration could be implemented with the high frequency (9 MHz) beam focused at 2 cm and the low frequency (6 MHz) beam focused again at 4 cm. In some applications, this approach may be advantageous in that the focusing ability of the beam former may allow a given frequency to potentially realize a deeper depth.

As described in greater detail below, the high frequency color frame and the low frequency color frame may be used in conjunction with weighting functions or other such means to form a composite color Doppler image with improved resolution across the entire

depth of the image, while the echo frame provides a grey-scale picture suitable for use as the background of the image.

FIGURE 4 illustrates the essential elements of one non-limiting embodiment of a system **301** that may be utilized in the color Doppler imaging techniques disclosed herein. The particular system illustrated assumes the use of two transmit beams, one at high frequency and the other at low frequency, though one skilled in the art will appreciate that the techniques disclosed herein can be readily generalized to systems that utilizes more than two transmit beam frequencies.

The system includes a beam former front end **303**, which transmits signals in order to form an image by shooting lines. A receiver, or Quadrature Band Pass (QBP) filter **305**, receives the echoes of the transmitted signals, and converts the received signals into complex numbers that are obtained from the product of the input signal with cosine and sine signals. The resulting complex numbers are input into a clutter filter **307**, which corrects for the wall motion of the subject. A power and autocorrelation function **309** is provided which takes multiple pulse repetition intervals (PRIs) and creates a complex frequency estimate from the average phase. This frequency estimate is related to the actual Doppler velocity by the Doppler equation.

The system further includes a multizone frame averaging functionality **311**, a lateral interpolation and spatial averaging functionality **313**, and mean frequency estimation **315** functionalities. The multizone frame averaging, by which two or more signals are essentially blended together, involves application of a complex signal estimate $S(t)$ **317**, which is given by EQUATION I:

$$S(t) = P * a(d) * S(t-1) + (1-P) * b(d) * S(t) \quad (\text{EQUATION 1})$$

wherein

- $a(d)$ is the depth and low frequency dependent weighting;
- $b(d)$ is the depth and high frequency dependent weighting; and
- P is the frame averaging coefficient.

The use, in the frame averaging process, of low and high frequency weighting factors that are depth dependent preserves near field resolution by preventing the low frequency signal from masking the near field resolution, while also preventing the high frequency signal from causing a loss in sensitivity. The result is a reasonably continuous signal resulting from the smooth blending of the low and high frequency signals. Absent a

weighting factor, signal loss is observable with the high frequency signal at a certain depth (typically on the order of a few centimeters), and the switch to a lower frequency signal produces a discontinuity.

5 The lateral interpolation and spatial averaging 313 functionality is provided to improve signal to noise ratio. This is preferably accomplished by averaging the signals laterally and axially. The mean frequency estimation 315 functionality derives the phase of the angle from its arctangent. The phase is then converted into a velocity.

10 Various options are possible to produce an even smoother transition from one signal to the other (that is, to create a more optimal blending of low and high frequency signals, in the case of a two signal solution). Thus, for example, the QDB can be operated as a function of depth to highlight the frequency present at a given depth.

15 As previously indicated, the methodologies described herein are not particularly limited to any number of transmit beams operating at different frequencies. However, it is preferred that there are multiple transmit beams operating at different frequencies, and that each transmit beam has multiple (for example, 4) receive beams associated with it. If two frequencies are utilized, it is preferred that the frequencies utilized are separated by at least 2 MHz but no more than 7 MHz, though larger spreads may be acceptable if additional transmit beams operating at intermediate frequencies are utilized.

The frequencies of the transmit beams in a system which utilizes transmit beams having first (F_1) and second (F_2) transmit frequencies are preferably selected such that, for the respective velocities V_1 and V_2 , the condition

$$V_1 = V_2 \quad (\text{EQUATION 2})$$

5 is true, wherein

$$V_1 = \text{PRF}_1 \cdot c / (2F_1 \cos(\theta)) \quad (\text{EQUATION 3})$$

and

$$V_2 = \text{PRF}_2 \cdot c / (2F_2 \cos(\theta)) \quad (\text{EQUATION 4})$$

and wherein:

- 10 PRF_1 is the color Doppler pulse repetition frequency associated with F_1 ;
 PRF_2 is the color Doppler pulse repetition frequency associated with F_2 ;
 θ is the color Doppler angle (typically constant); and
 c is the speed of sound.

FIGURE 5 illustrates one specific, non-limiting example of a beam pattern **401** that can be employed in the imaging methodologies disclosed herein. The beam pattern has not been drawn to scale. The beam pattern is a 4-way parallel beam pattern that includes a transmit beam **403** and receive beams **405**, **407**, **409** and **411**. In a typical embodiment of the methodologies disclosed herein, multiple transmit beams will be utilized, each of which may have a beam pattern of the type illustrated.

20 In some embodiments, the integrated energy of receive beams **405** and **409** may be compared in order to determine which way, if any, to adjust the center of each receive aperture in the elevation direction, should any adjustments be necessary to compensate for occlusions. Similarly, the integrated energy of receive beams **407** and **411** may be compared in order to determine which way, if any, to adjust the center of each receive
 25 aperture laterally.

FIGURE 6 shows a simplified block diagram of one possible ultrasound imaging system **10** that may be used in the implementation of the methodologies disclosed herein. It will be appreciated by those of ordinary skill in the relevant arts that the ultrasound imaging system **10**, as illustrated in **FIGURE 6**, and the operation thereof as described
 30 hereinafter, is intended to be generally representative of such systems and that any particular system may differ significantly from that shown in **FIGURE 6**, particularly in the details of construction and in the operation of such system. As such, the ultrasound

imaging system **10** is to be regarded as illustrative and exemplary, and not limiting, as regards the methodologies and devices described herein or the Claims attached hereto.

The ultrasound imaging system **10** generally includes an ultrasound unit **12** and a connected transducer **14**. The transducer **14** includes a spatial locator receiver **16**. The
5 ultrasound unit **12** has integrated therein a spatial locator transmitter **18** and an associated controller **20**. The controller **20** provides overall control of the system by providing timing and control functions. The control routines include a variety of routines that modify the operation of the receiver **16** so as to produce a volumetric ultrasound image as a live real-time image, a previously recorded image, or a paused or frozen image for
10 viewing and analysis.

The ultrasound unit **12** is also provided with an imaging unit **22** for controlling the transmission and receipt of ultrasound, and an image processing unit **24** for producing a display on a monitor (See **FIGURE 7**). The image processing unit **24** contains routines for rendering a three-dimensional image. The transmitter **18** is preferably located in an upper
15 portion of ultrasound unit **12** so as to obtain a clear transmission to the receiver **16**. Although not specifically illustrated, the ultrasound unit described herein may be configured in a cart format.

During freehand imaging, a technician moves the transducer **14** over the subject **25** in a controlled motion. The ultrasound unit **12** combines image data produced by the
20 imaging unit **22** with location data produced by the controller **20** to produce a matrix of data suitable for rendering onto a monitor (see **FIGURE 7**). The ultrasound imaging system **10** integrates image rendering processes with image processing functions using general purpose processors and PC-like architectures. On the other hand, use of ASICs to perform the stitching and rendering is possible.

FIGURE 7 is a block diagram **30** of an ultrasound system that may be used in the practice of the methodologies disclosed herein. The ultrasound imaging system shown in **FIGURE 11** is configured for the use of pulse generator circuits, but could be equally configured for arbitrary waveform operation. The ultrasound imaging system **10** uses a centralized architecture suitable for the incorporation of standard personal computer ("PC")
25 type components and includes a transducer **14** which, in a known manner, scans an ultrasound beam, based on a signal from a transmitter **28**, through an angle. Backscattered signals or echoes are sensed by the transducer **14** and fed, through a receive/transmit
30

switch 32, to a signal conditioner 34 and, in turn, to a beam former 36. The transducer 14 includes elements which are preferably configured as a steerable, two-dimensional array. The signal conditioner 34 receives backscattered ultrasound signals and conditions those signals by amplification and forming circuitry prior to their being fed to the beam former 36. Within the beam former 36, ultrasound signals are converted to digital values and are configured into "lines" of digital data values in accordance with amplitudes of the backscattered signals from points along an azimuth of the ultrasound beam.

The beam former 36 feeds digital values to an application specific integrated circuit (ASIC) 38 which incorporates the principal processing modules required to convert digital values into a form more conducive to video display that feeds to a monitor 40. A front end data controller 42 receives lines of digital data values from the beam former 36 and buffers each line, as received, in an area of the buffer 44. After accumulating a line of digital data values, the front end data controller 42 dispatches an interrupt signal, via a bus 46, to a shared central processing unit (CPU) 48. The CPU 48 executes control procedures 50 including procedures that are operative to enable individual, asynchronous operation of each of the processing modules within the ASIC 38. More particularly, upon receiving an interrupt signal, the CPU 48 feeds a line of digital data values residing in a buffer 42 to a random access memory (RAM) controller 52 for storage in random access memory (RAM) 54 which constitutes a unified, shared memory. RAM 54 also stores instructions and data for the CPU 48 including lines of digital data values and data being transferred between individual modules in the ASIC 38, all under control of the RAM controller 52.

The transducer 14, as mentioned above, incorporates a receiver 16 that operates in connection with a transmitter 28 to generate location information. The location information is supplied to (or created by) the controller 20 which outputs location data in a known manner. Location data is stored (under the control of the CPU 48) in RAM 54 in conjunction with the storage of the digital data value.

Control procedures 50 control a front end timing controller 45 to output timing signals to the transmitter 28, the signal conditioner 34, the beam former 36, and the controller 20 so as to synchronize their operations with the operations of modules within the ASIC 38. The front end timing controller 45 further issues timing signals which control the operation of the bus 46 and various other functions within the ASIC 38.

As previously noted, control procedures 50 configure the CPU 48 to enable the front end data controller 44 to move the lines of digital data values and location information into the RAM controller 52, where they are then stored in RAM 54. Since the CPU 48 controls the transfer of lines of digital data values, it senses when an entire image frame has been stored in RAM 54. At this point, the CPU 48 is configured by control procedures 50 and recognizes that data is available for operation by a scan converter 58. At this point, therefore, the CPU 48 notifies the scan converter 58 that it can access the frame of data from RAM 54 for processing.

To access the data in RAM 54 (via the RAM controller 52), the scan converter 58 interrupts the CPU 48 to request a line of the data frame from RAM 54. Such data is then transferred to a buffer 60 associated with the scan converter 58 and is transformed into data that is based on an X-Y coordinate system. When this data is coupled with the location data from the controller 20, a matrix of data in an X-Y-Z coordinate system results. A four-dimensional matrix may be used for 4-D (X-Y-Z-time) data. This process is repeated for subsequent digital data values of the image frame from RAM 54. The resulting processed data is returned, via the RAM controller 52, into RAM 54 as display data. The display data is typically stored separately from the data produced by the beam former 36. The CPU 48 and control procedures 50, via the interrupt procedure described above, sense the completion of the operation of the scan converter 58. The video processor 62 interrupts the CPU 48 which responds by feeding lines of video data from RAM 54 into the buffer 62, which is associated with the video processor 64. The video processor 64 uses video data to render a three-dimensional volumetric ultrasound image as a two-dimensional image on the monitor 40.

The above description of the invention is illustrative, and is not intended to be limiting. It will thus be appreciated that various additions, substitutions and modifications may be made to the above described embodiments without departing from the scope of the present invention. Accordingly, the scope of the present invention should be construed solely in reference to the appended Claims.

CLAIMS:

1. A method for producing color Doppler images of a subject, comprising the steps of:
transmitting first and second transmit beams into the subject, wherein said first and second transmit beams are characterized by first and second frequencies, and wherein each of said first and second transmit beams has first and second sets of receive beams associated therewith, respectively;
receiving the first and second sets of receive beams; and
producing a composite color Doppler image based on the first and second sets of receive beams.
2. The method of Claim 1, wherein the composite image is produced by interleaving first and second frames derived, respectively, from the first and second sets of receive beams.
3. The method of Claim 1, wherein the composite image is derived from the weighted average of the first and second sets of receive beams.
4. The method of Claim 3, wherein the weighted average is derived by applying first and second weighting factors to the first and second sets of receive beams, respectively.
5. The method of Claim 4, wherein the first and second weighting factors are chosen to optimize sensitivity and near field resolution.
6. The method of Claim 1, wherein the first frequency is a high frequency and the second frequency is a low frequency.
7. The method of Claim 1, wherein the difference between the first and second frequencies is at least about 2 MHz.
8. The method of Claim 2, wherein the first and second frames are derived from frequency estimates based on the first and second sets of receive beams.
9. The method of Claim 3, wherein the composite image is derived from frequency estimates corresponding to the first and second sets of receive beams.
10. The method of Claim 8, wherein the composite image is formed by averaging the complex signal estimates used to produce the frequency estimate for the first set of receive beams with the complex signal estimates used to produce the frequency estimate for the second set of receive beams.
11. The method of Claim 10, wherein the composite image is a color Doppler image.

12. The method of Claim 11, wherein the first (F_1) and second (F_2) frequencies are such that $V_1 = V_2$, wherein

$$V_1 = \text{PRF}_1 \cdot c / (2F_1 \cos(\theta)) \text{ and}$$

$$V_2 = \text{PRF}_2 \cdot c / (2F_2 \cos(\theta)),$$

and wherein:

PRF_1 is the color Doppler pulse repetition frequency associated with F_1 ;

PRF_2 is the color Doppler pulse repetition frequency associated with F_2 ;

θ is the color Doppler angle; and

c is the speed of sound.

13. The method of Claim 12, wherein θ is constant.

14. The method of Claim 1, wherein each of the first and second sets of receive beams has a plurality of members.

15. A method for acoustically imaging a subject, comprising the steps of:

transmitting first and second transmit beams into the subject, wherein the first and second transmit beams are characterized by first and second frequencies F_1 and F_2 , respectively, wherein $F_1 > F_2$;

receiving first and second sets of receive beams corresponding, respectively, to first and second transmit beams;

determining the frequencies of the first and second sets of receive beams;

applying first and second weighting factors to the determined frequencies, thereby producing first and second weighted frequencies; and

producing a composite color Doppler image based on the first and second weighted frequencies.

16. The method of Claim 15, wherein each of said first and second sets of receive beams has a plurality of members.

17. A method for producing color Doppler images of a subject, comprising the steps of:

obtaining a grey scale image frame from the subject;

obtaining a first color image frame from the subject by transmitting a first transmit beam into the subject and receiving a first set of receive beams that are associated with the first transmit beam, wherein said first transmit beam is characterized by a first frequency and has a first set of receive beams associated therewith;

obtaining a second color image frame from the subject by transmitting a second transmit beam into the subject, wherein said second transmit beam is characterized by a second frequency and has a second set of receive beams associated therewith, wherein said second frequency is distinct from said first frequency;

receiving the first and second sets of receive beams; and

producing a composite color Doppler image based on the first and second sets of receive beams.

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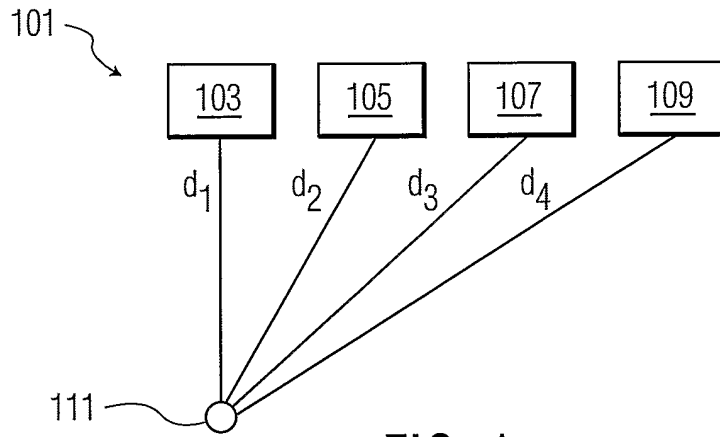


FIG. 1

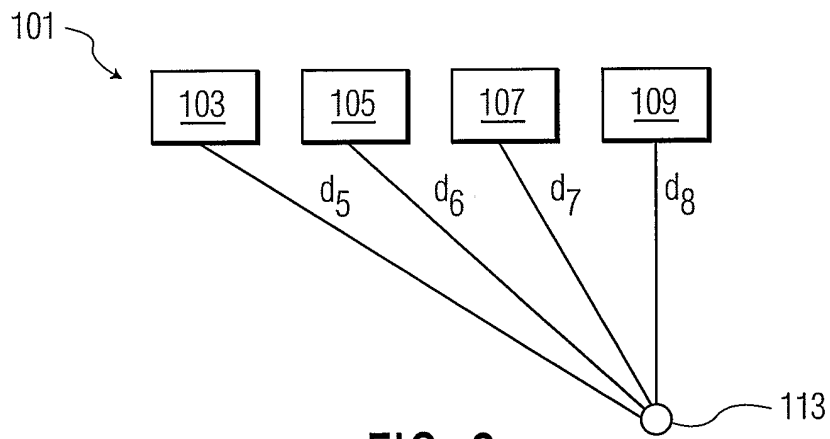


FIG. 2

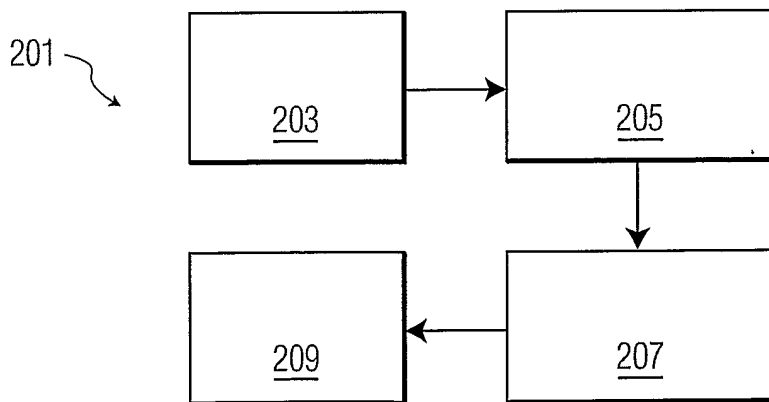


FIG. 3

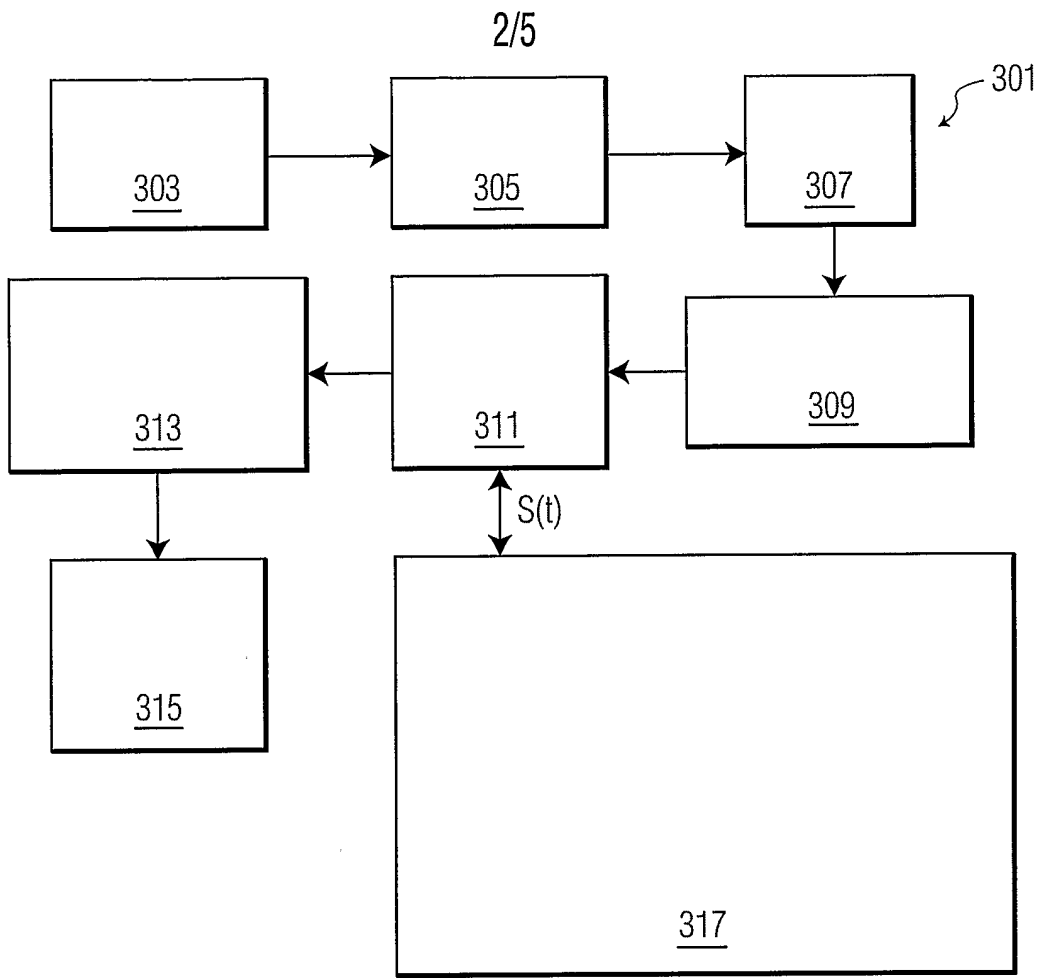


FIG. 4

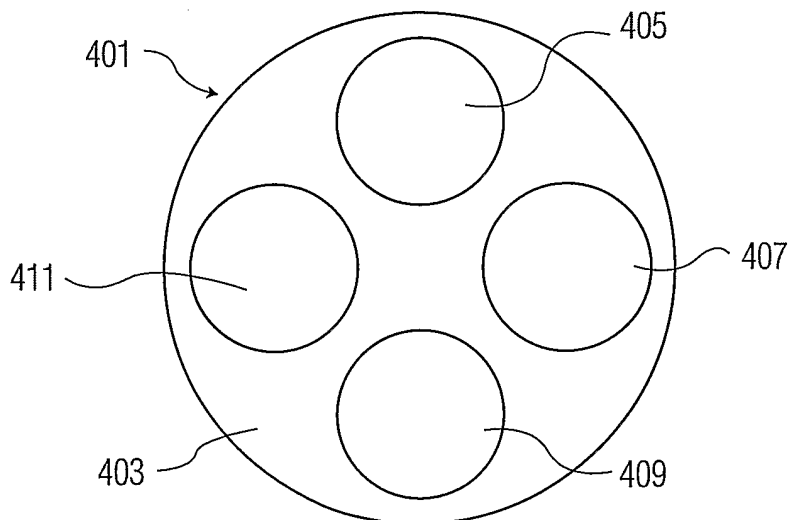


FIG. 5

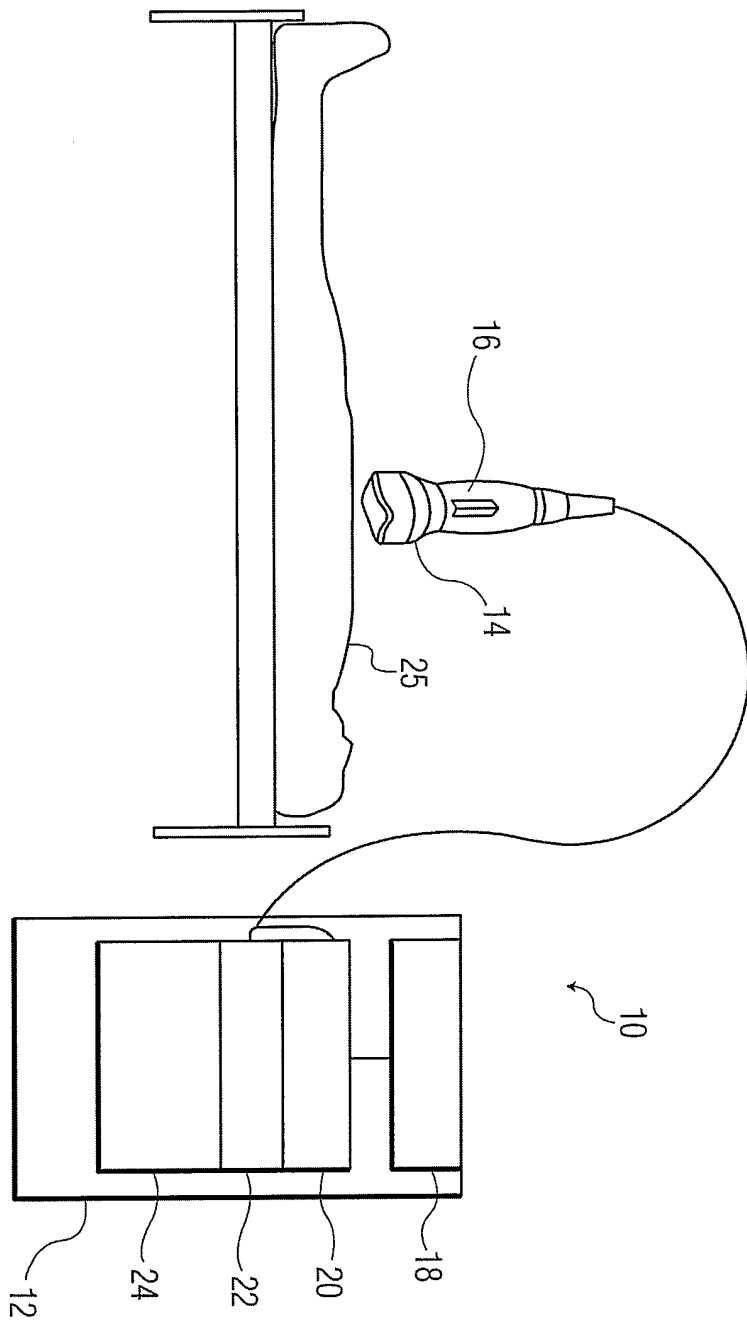


FIG. 6

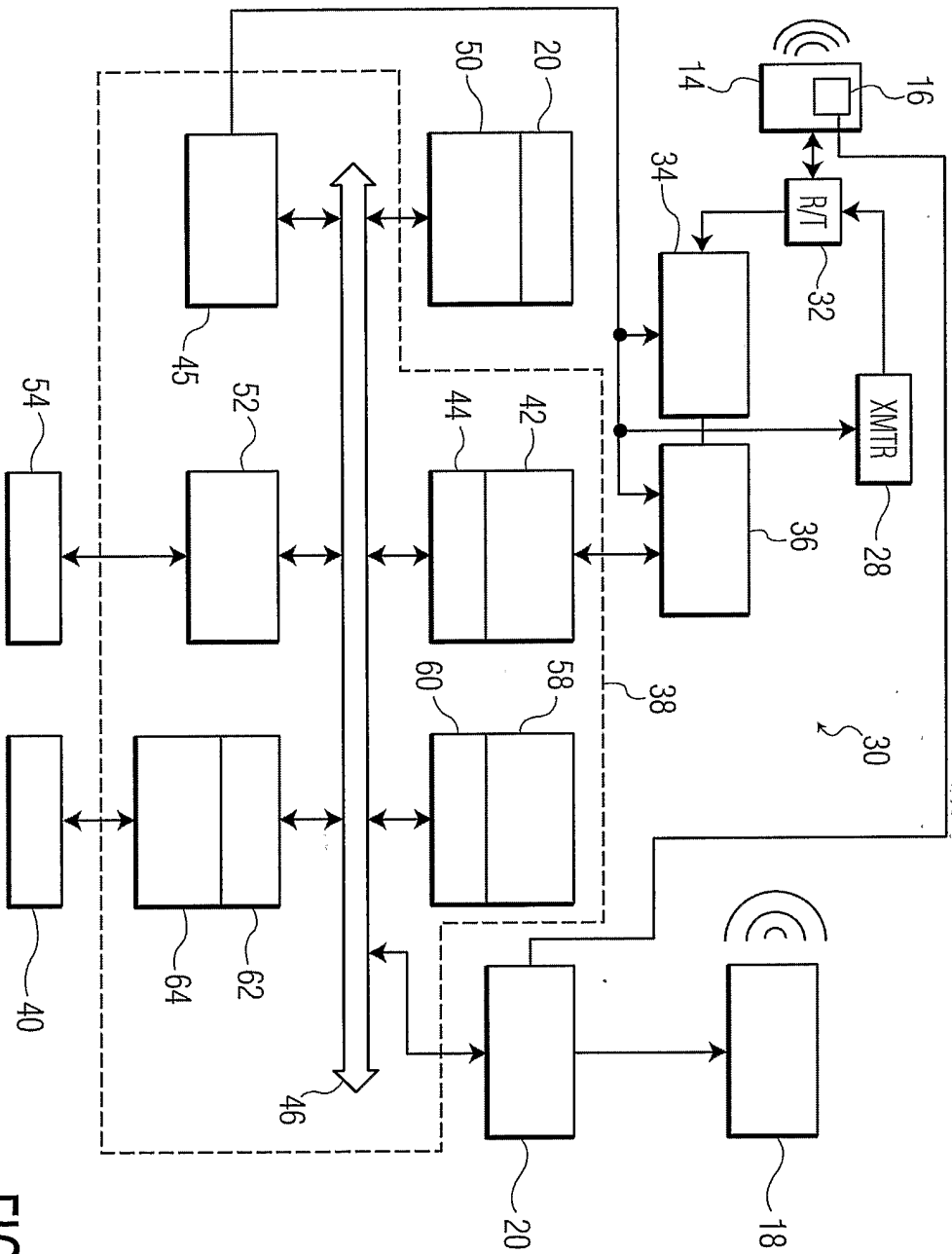


FIG. 7

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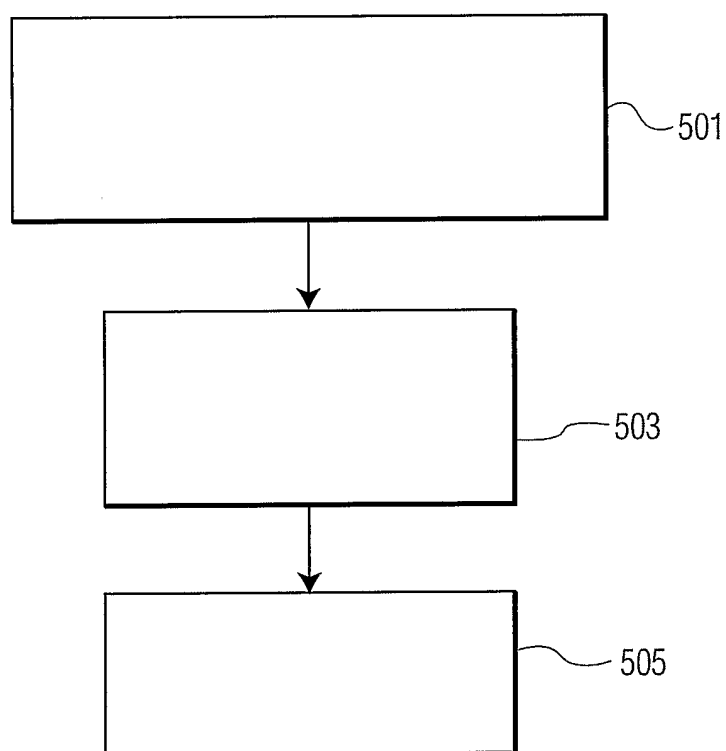


FIG. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB2005/051238

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S15/89 G01S7/52

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, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 6 645 146 B1 (ADAMS QIAN ZHANG ET AL) 11 November 2003 (2003-11-11) abstract; figures 2-8 column 1, line 57 - column 5, line 10 -----	1, 3-7, 9, 14-17 2, 8, 10-13
X Y	US 2002/040188 A1 (AVERKIOU MICHALAKIS) 4 April 2002 (2002-04-04) abstract; figures 1-2b, 9 paragraphs '0004!, '0024!, '0028! - '0037!, '0049! - '0053! ----- -/--	1, 3-7, 9, 14-17 2, 8, 10-13

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

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Date of the actual completion of the international search

3 June 2005

Date of mailing of the international search report

21/06/2005

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INTERNATIONAL SEARCH REPORT

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Y	US 6 390 980 B1 (PETERSON ROY B ET AL) 21 May 2002 (2002-05-21) abstract; figures 3,7-10c column 1, line 35 - column 2, line 4 column 3, line 36 - column 4, line 28 column 6, line 31 - column 11, line 50 -----	2,8, 10-13
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