US 20100010350A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2010/0010350 A1

(43) Pub. Date: Jan. 14, 2010

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(54) ULTRASONIC DIAGNOSTIC APPARATUS AND ULTRASONIC IMAGE ACQUISITION METHOD

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(21) Appl. No.: **12/501,736**

(22) Filed: **Jul. 13, 2009**

(30) **Foreign Application Priority Data**

Jul. 14, 2008 (JP) 2008-183137
Jul. 1, 2009 (JP) 2009-157067

Publication Classification

(51) **Int. Cl.**
A61B 8/14 (2006.01)

(52) **U.S. Cl.** **600/443**

(57) **ABSTRACT**

Real-time display of a three-dimensional ultrasonic image in which there is little time delay, power required for transmission of an ultrasonic wave is reduced, and heterogeneousness of received beams is almost solved is performed by executing multi-beam reception while performing frequency demodulation of a reflected wave obtained as a result of transmission of a frequency-modulated continuous ultrasonic wave to the subject body. As a demodulation method, for example, a multi-phase demodulation method of obtaining the distance resolution in multi-beam reception by performing (multi-phase) demodulation while changing the phases of transmission modulation and reception modulation for every range in the range direction (beam direction).

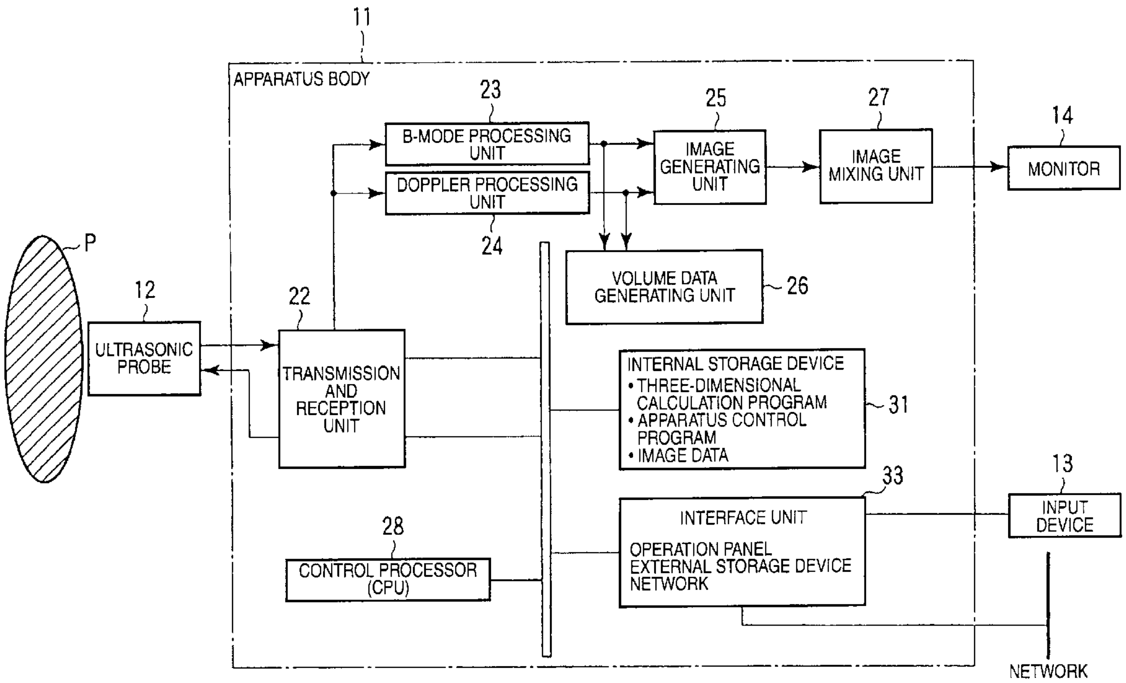


FIG. 1

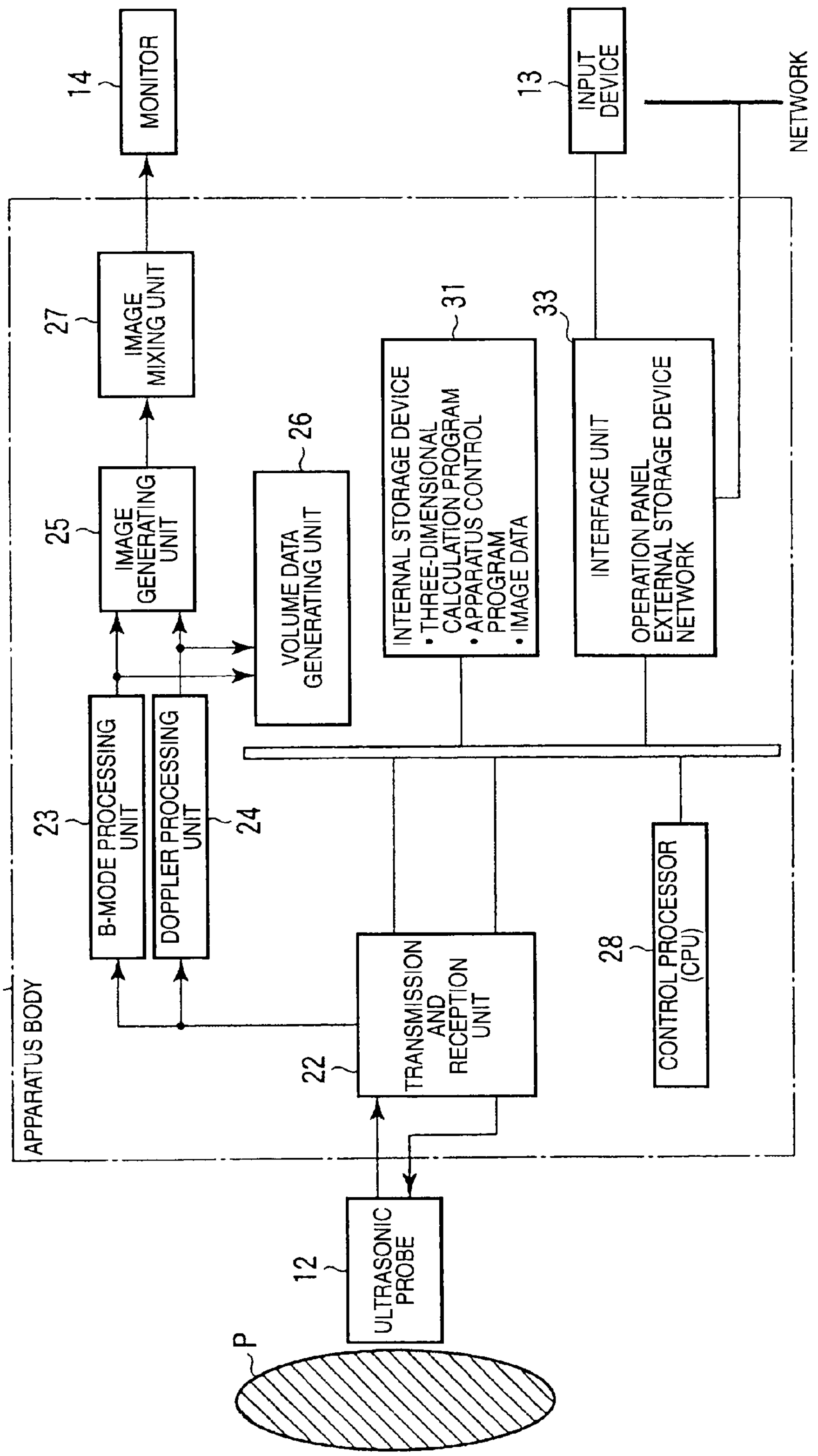

MONITOR
14
INPUT DEVICE
13
NETWORK
IMAGE MIXING UNIT
27
INTERNAL STORAGE DEVICE
• THREE-DIMENSIONAL CALCULATION PROGRAM
• APPARATUS CONTROL PROGRAM
• IMAGE DATA
31
INTERFACE UNIT
OPERATION PANEL
EXTERNAL STORAGE DEVICE
NETWORK
33
IMAGE GENERATING UNIT
25
VOLUME DATA GENERATING UNIT
26
B-MODE PROCESSING UNIT
23
DOPPLER PROCESSING UNIT
24
APPARATUS BODY
11
TRANSMISSION AND RECEPTION UNIT
22
CONTROL PROCESSOR (CPU)
28
ULTRASONIC PROBE
12
P

FIG. 2

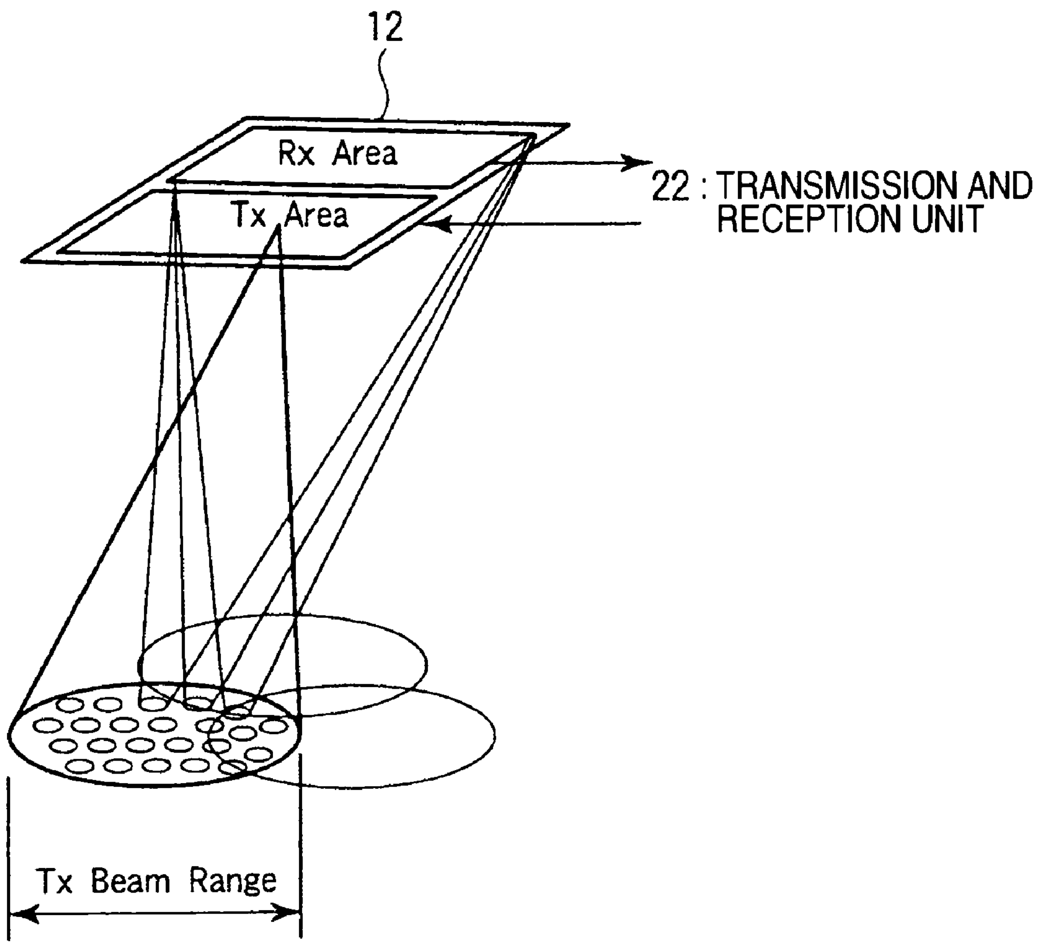

12
Rx Area
Tx Area
22 : TRANSMISSION AND RECEPTION UNIT
Tx Beam Range

FIG. 3

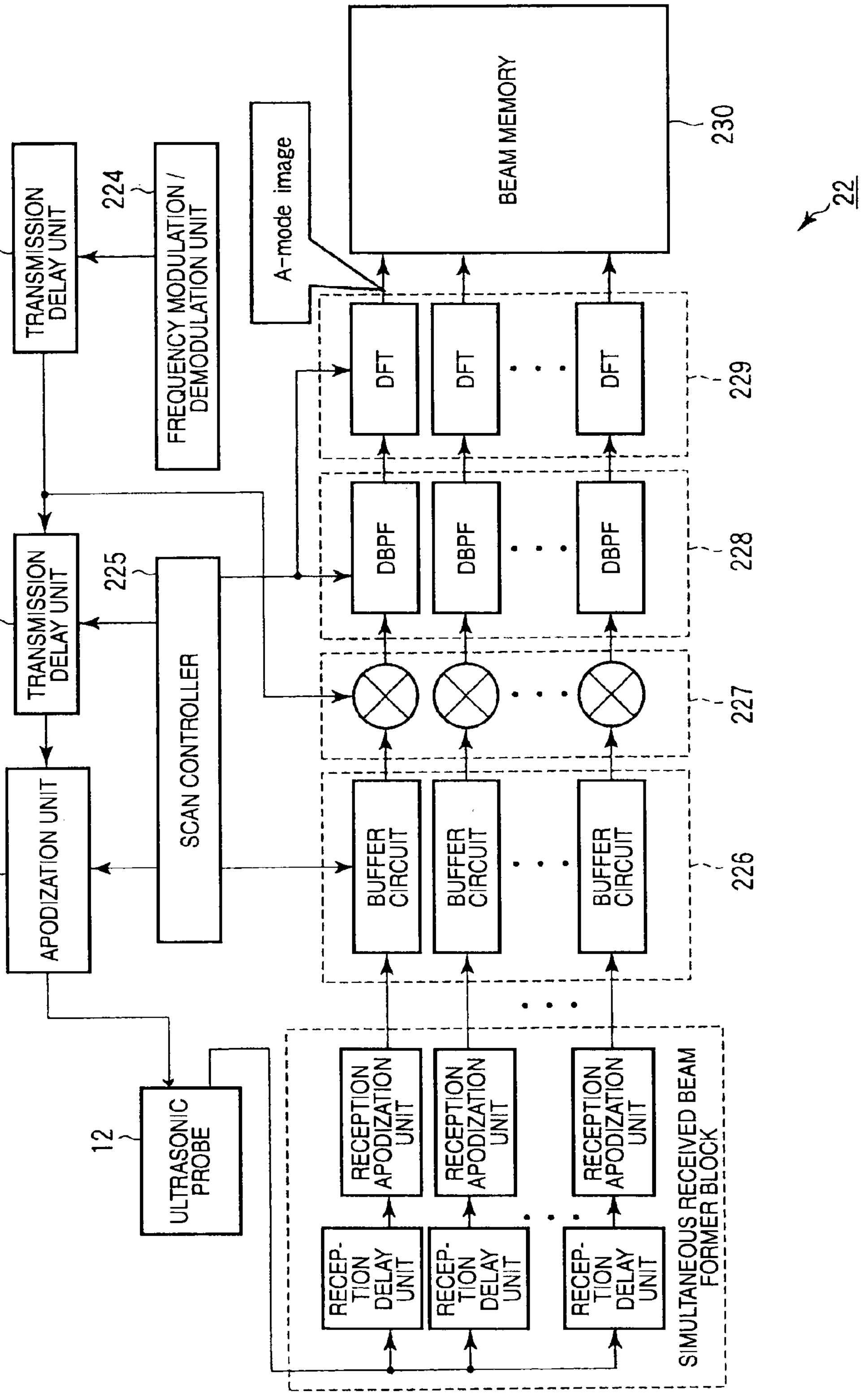

220
TRANSMISSION DELAY UNIT
224
FREQUENCY MODULATION / DEMODULATION UNIT
A-mode image
BEAM MEMORY
230
22
222
TRANSMISSION DELAY UNIT
225
SCAN CONTROLLER
223
APODIZATION UNIT
12
ULTRASONIC PROBE
DFT
229
DBPF
228
227
BUFFER CIRCUIT
226
RECEPTION APODIZATION UNIT
RECEP-TION DELAY UNIT
SIMULTANEOUS RECEIVED BEAM FORMER BLOCK

FIG. 4

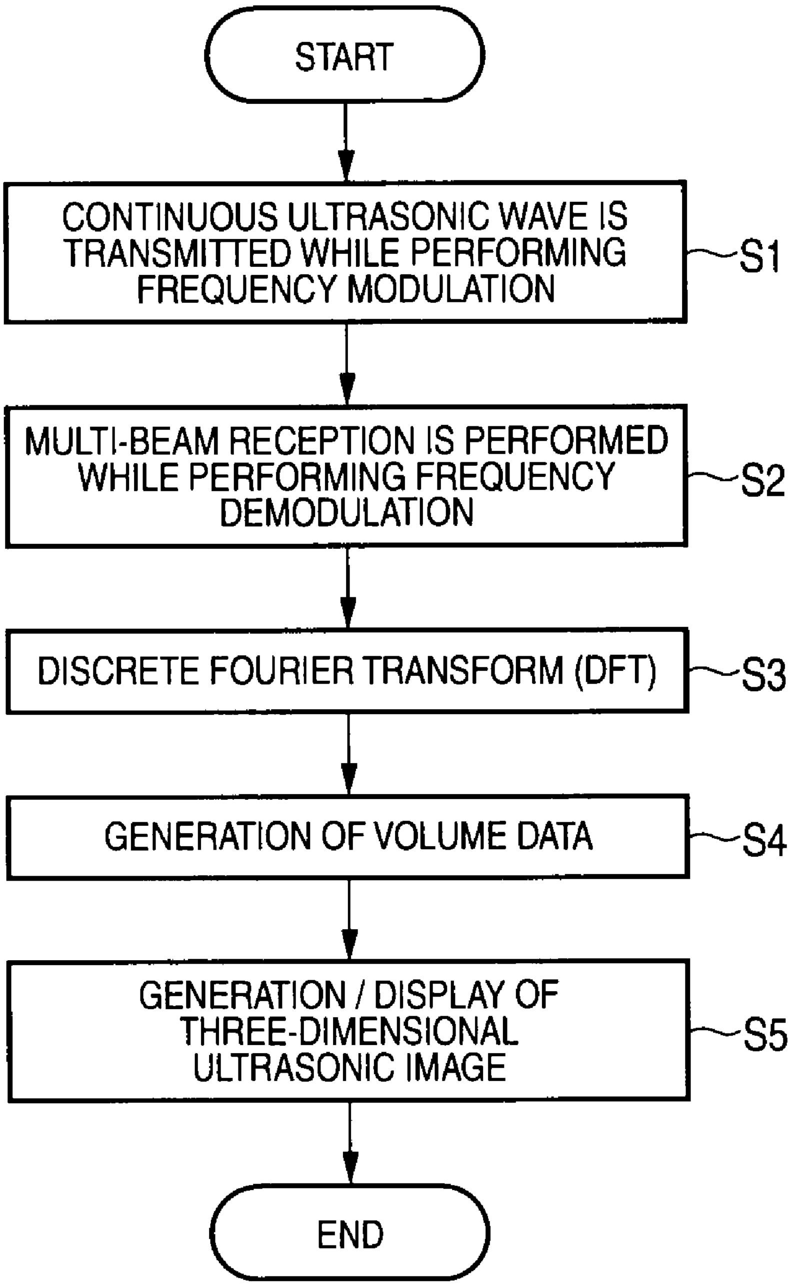

START
CONTINUOUS ULTRASONIC WAVE IS TRANSMITTED WHILE PERFORMING FREQUENCY MODULATION
S1
MULTI-BEAM RECEPTION IS PERFORMED WHILE PERFORMING FREQUENCY DEMODULATION
S2
DISCRETE FOURIER TRANSFORM (DFT)
S3
GENERATION OF VOLUME DATA
S4
GENERATION / DISPLAY OF THREE-DIMENSIONAL ULTRASONIC IMAGE
S5
END

FIG. 5

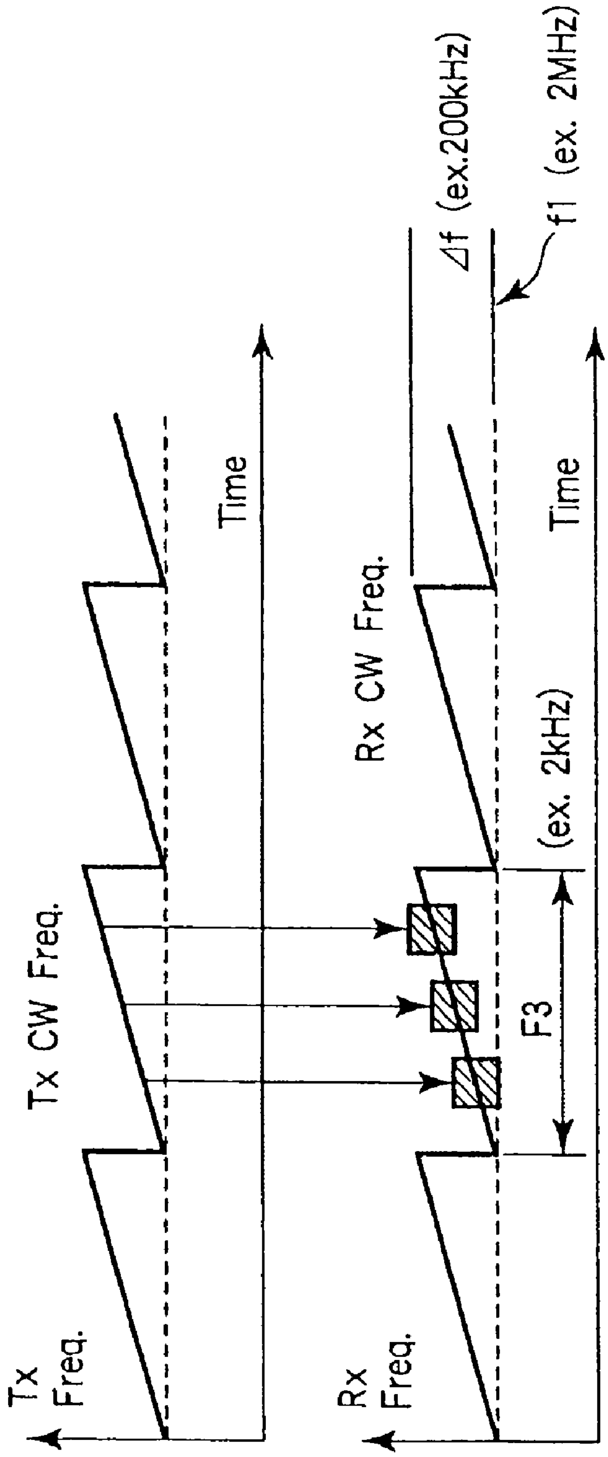

Tx Freq.
Tx CW Freq.
Time
Rx Freq.
Rx CW Freq.
Time
Δf (ex.200kHz)
f1 (ex. 2MHz)
F3
(ex. 2kHz)

FIG. 6

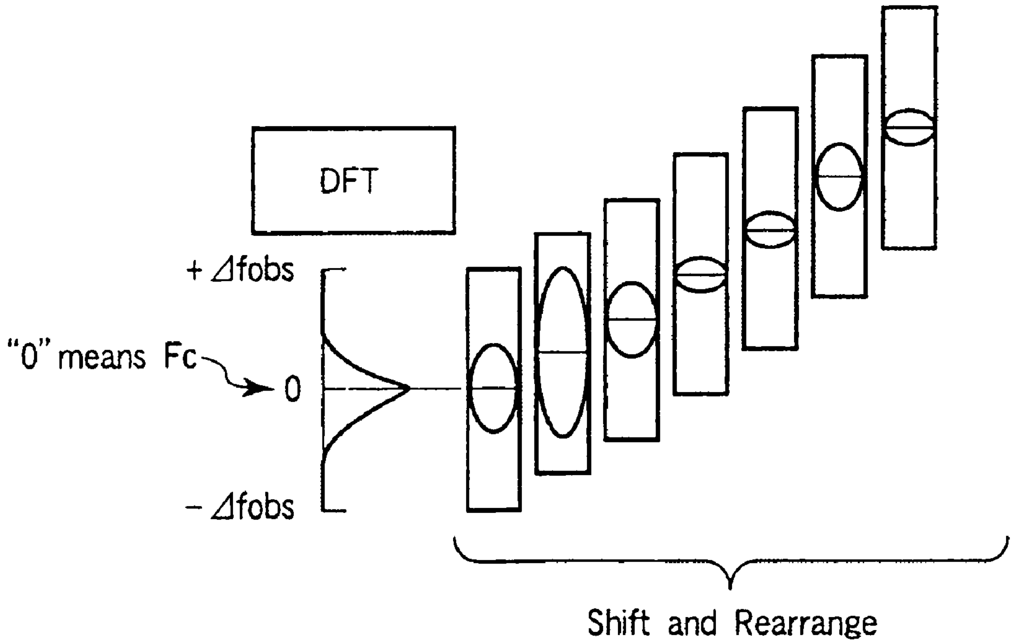


FIG. 7

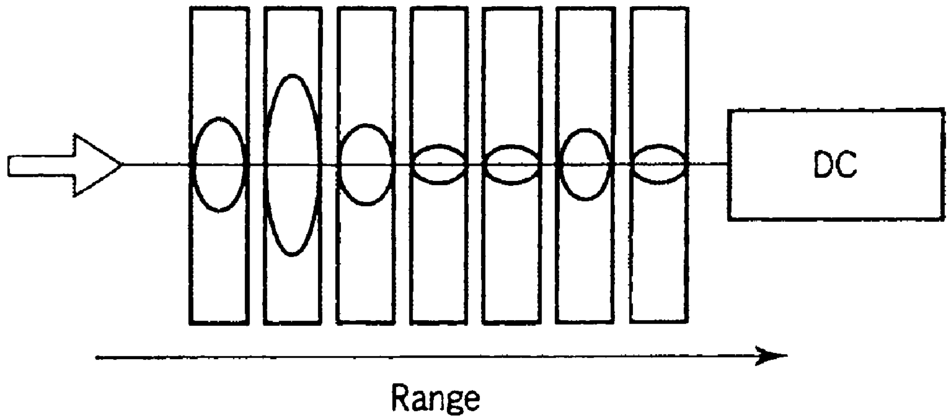


FIG. 8

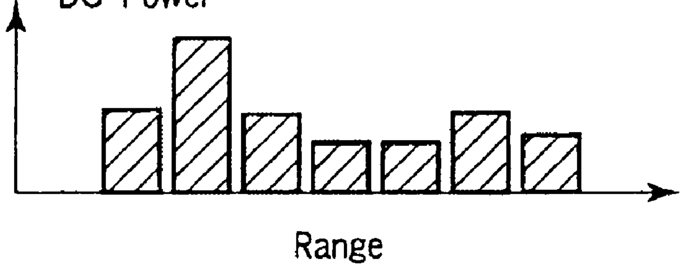


FIG. 9

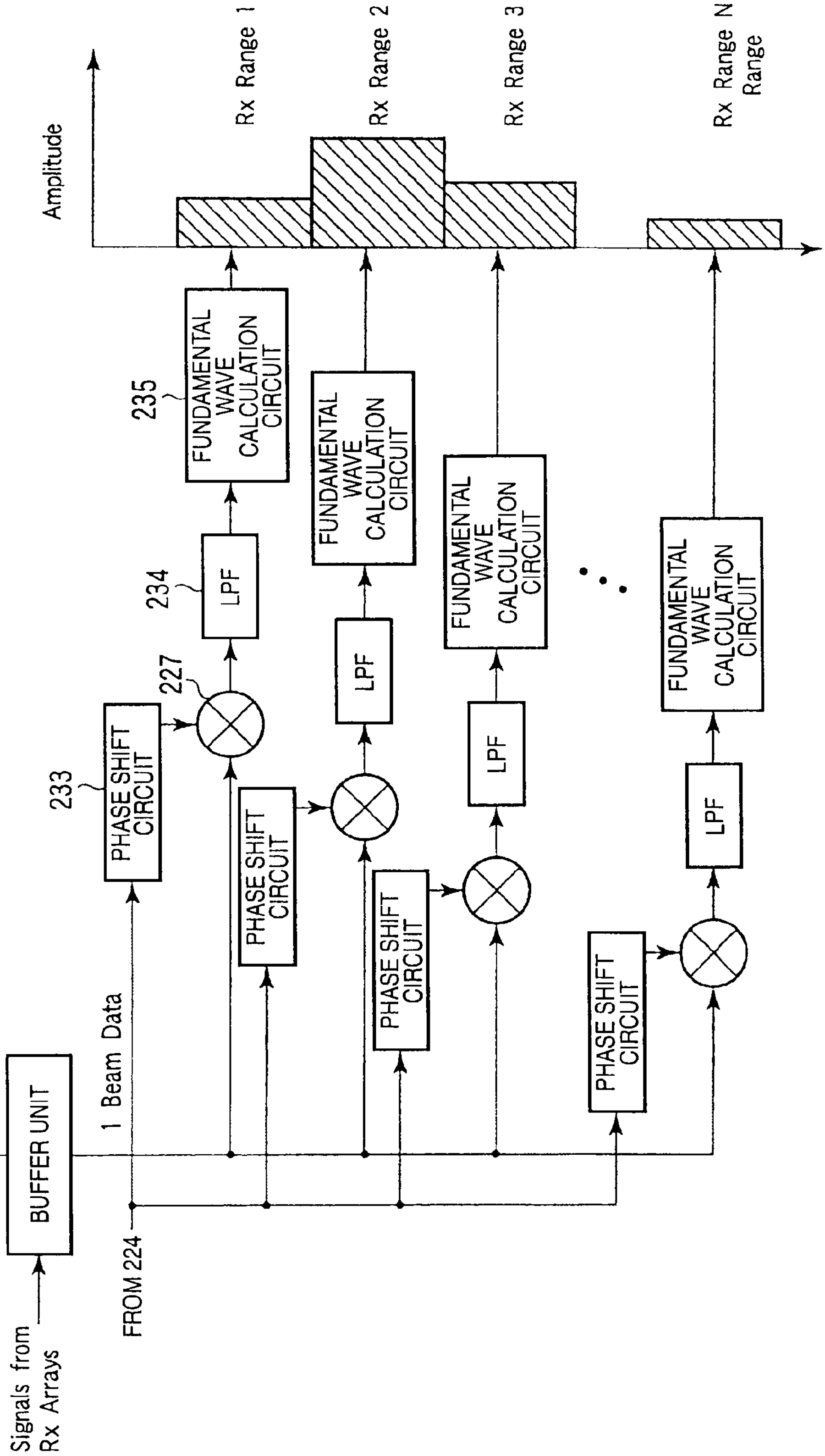

Signals from Rx Arrays
232
BUFFER UNIT
FROM 224
1 Beam Data
233
PHASE SHIFT CIRCUIT
227
234
LPF
235
FUNDAMENTAL WAVE CALCULATION CIRCUIT
Amplitude
Rx Range 1
Rx Range 2
Rx Range 3
Rx Range N Range

FIG. 10

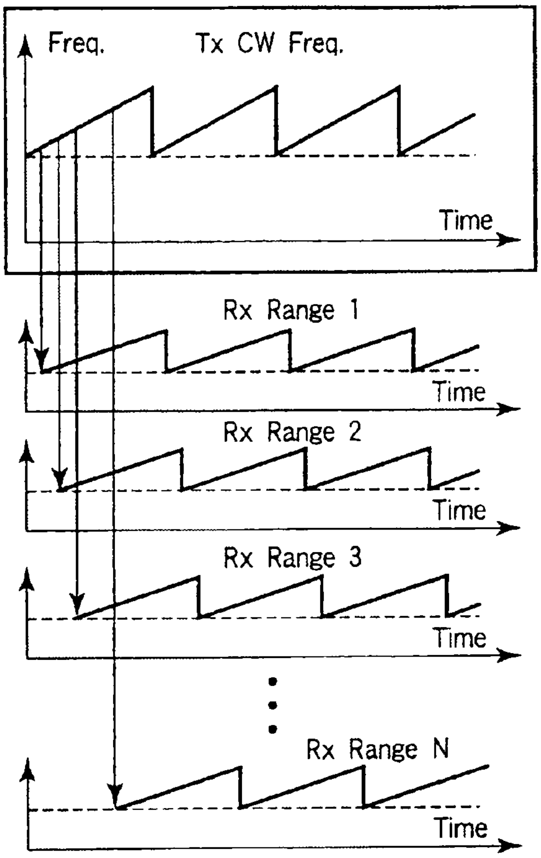

Freq.
Tx CW Freq.
Time
Rx Range 1
Time
Rx Range 2
Time
Rx Range 3
Time
Rx Range N
Time

FIG. 11

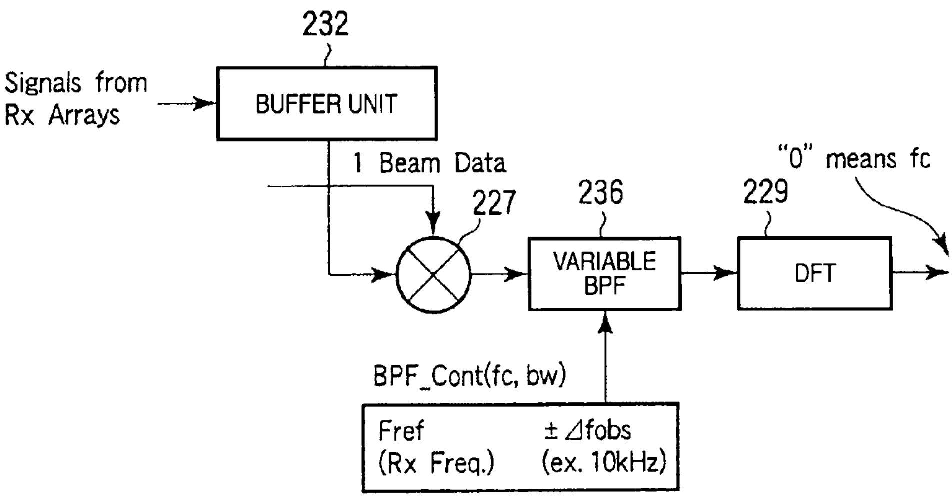

232
Signals from Rx Arrays
BUFFER UNIT
1 Beam Data
227
236
VARIABLE BPF
229
DFT
"0" means fc
BPF_Cont(fc, bw)
Fref (Rx Freq.)
± ⊿fobs (ex. 10kHz)

FIG. 12

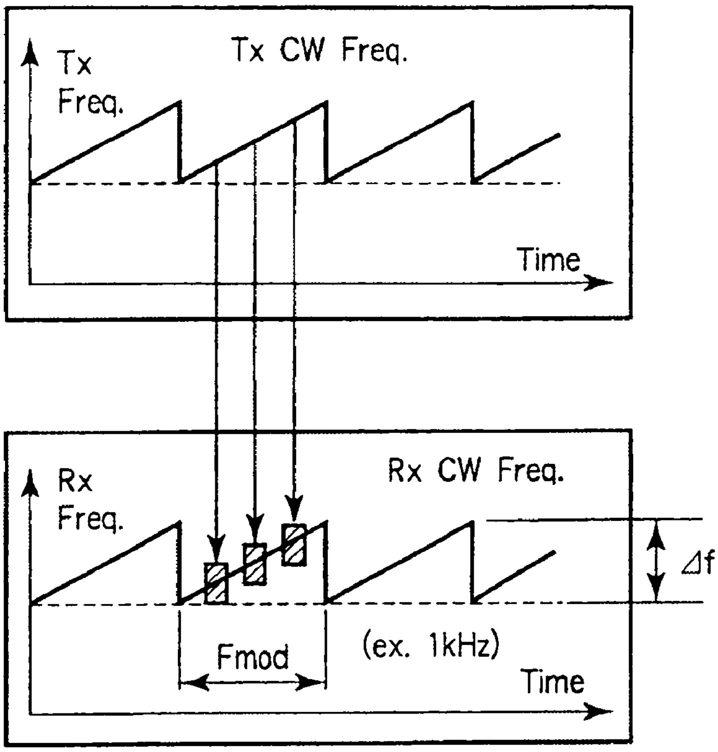

Tx CW Freq.
Tx
Freq.
Time
Rx CW Freq.
Rx
Freq.
Δf
Fmod
(ex. 1kHz)
Time

FIG. 13

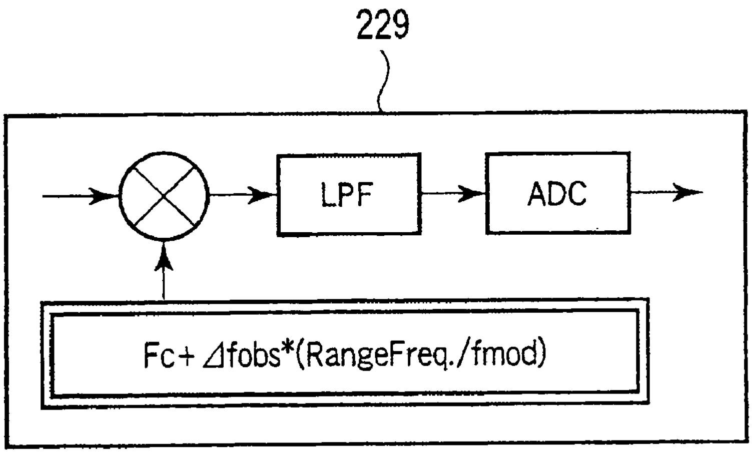

229
LPF
ADC
Fc+ Δfobs*(RangeFreq./fmod)

FIG. 14A

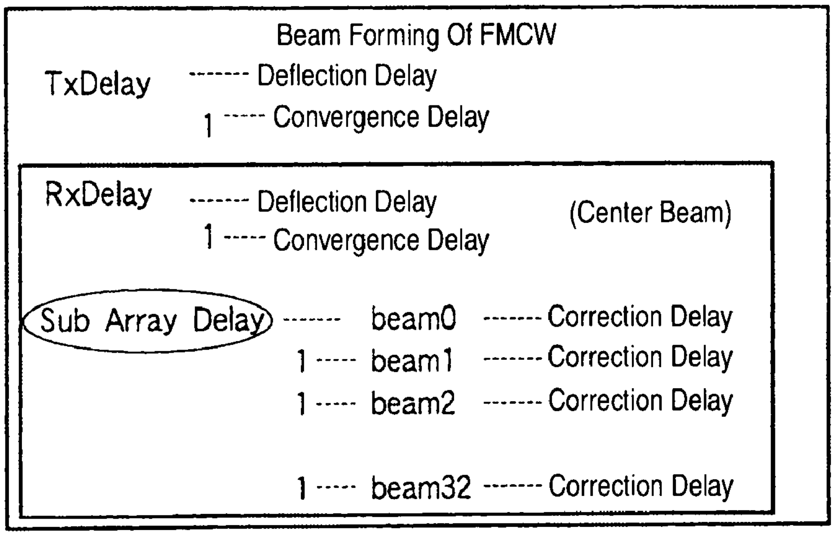


FIG. 14B

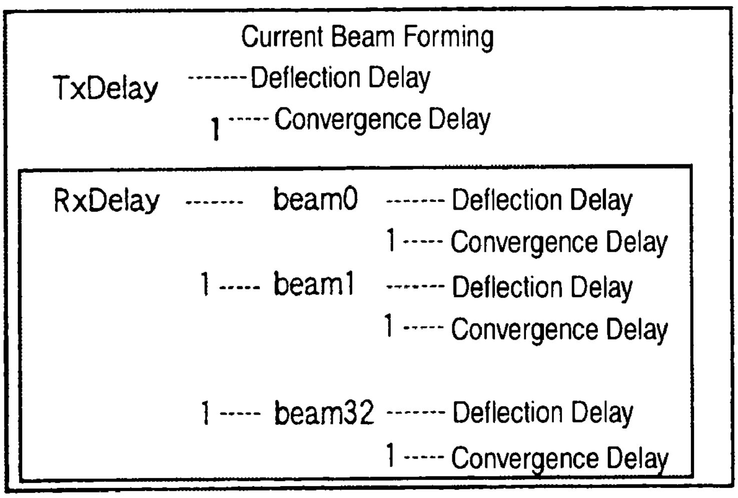
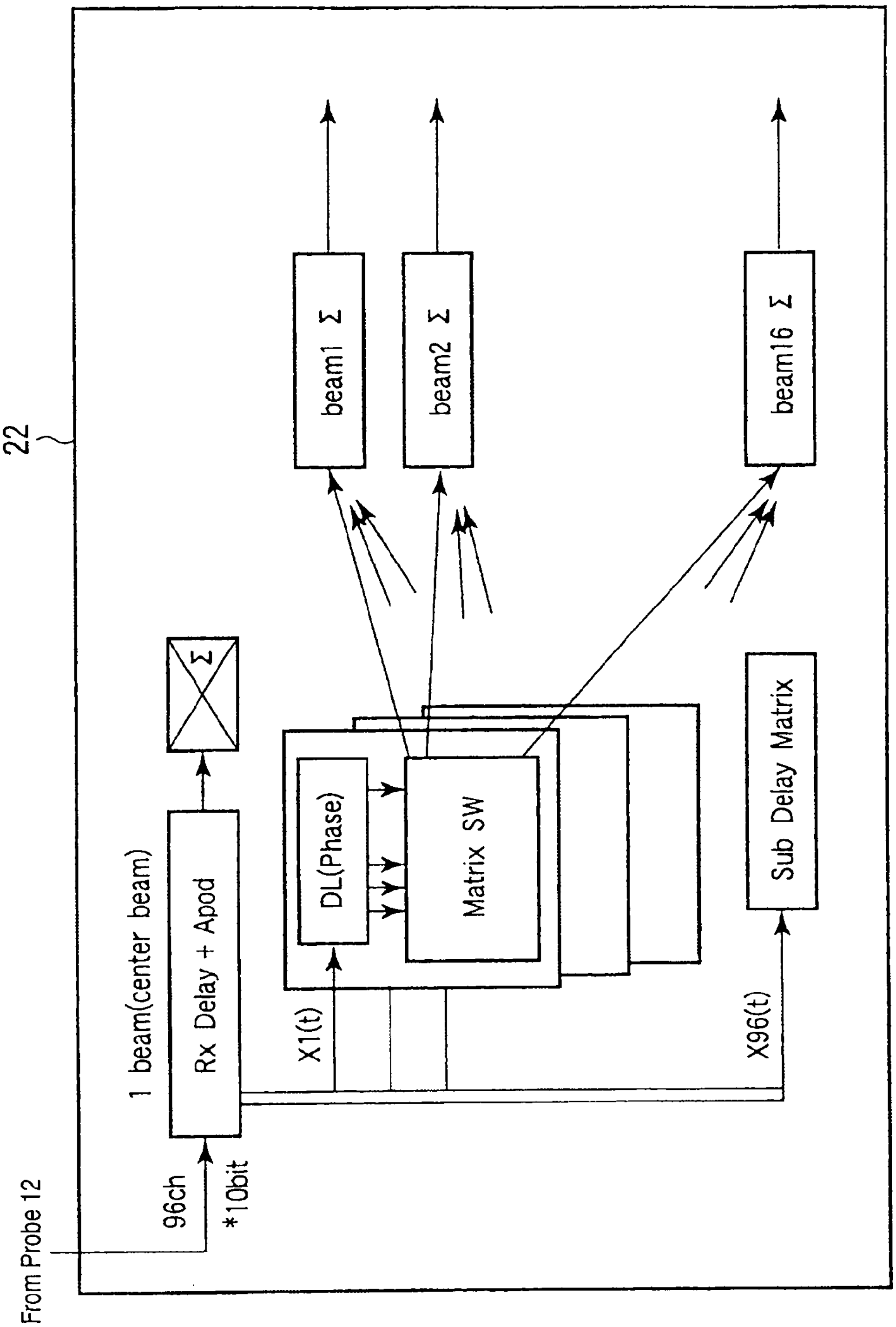


FIG. 15


22
From Probe 12
96ch
*10bit
1 beam(center beam)
Rx Delay + Apod
Σ
X1(t)
DL(Phase)
Matrix SW
X96(t)
Sub Delay Matrix
beam1 Σ
beam2 Σ
beam16 Σ

ULTRASONIC DIAGNOSTIC APPARATUS AND ULTRASONIC IMAGE ACQUISITION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from prior Japanese Patent Applications No. 2008-183137, filed Jul. 14, 2008; and No. 2009-157067, filed Jul. 1, 2009, the entire contents of both of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to an ultrasonic diagnostic apparatus and in particular, to an apparatus which executes continuous wave Doppler (CWD) using a continuous wave (CW) as an ultrasonic wave. Specifically, the present invention relates to an ultrasonic diagnostic apparatus and an ultrasonic image acquisition method capable of observing movement information of blood flow, which flows through a specific region in the distance direction, by giving the resolving power in the distance direction while making maximum use of the merit that there is no reflection due to the continuous wave Doppler.

[0004] 2. Description of the Related Art

[0005] The ultrasonic diagnosis allows pulsation of the heart or movement of an embryo to be displayed in real time by a simple operation of bringing an ultrasonic probe into contact with a body surface. In addition, since the ultrasonic diagnosis is very safe, the test may be performed repeatedly. In addition, the system size is small compared with other diagnostic apparatuses, such as an X ray, a CT, and an MRI, and a test can be easily performed at the bedside. For this reason, it can be said that the ultrasonic diagnosis is an easy diagnostic method. An ultrasonic diagnostic apparatus used in the ultrasonic diagnosis changes in various ways with the type of function that the ultrasonic diagnostic apparatus has. As a small ultrasonic diagnostic apparatus, an ultrasonic diagnostic apparatus that can be carried with one hand is being developed. In addition, since the ultrasonic diagnosis does not cause radioactive exposure unlike the X ray, the ultrasonic diagnosis may also be used in an obstetric treatment, a remote medical treatment, and the like.

[0006] For example such an ultrasonic diagnostic apparatus may be used to scan a three-dimensional region of the heart to image in three-dimensions in real time. When performing such imaging, there are restrictions in the sound speed in order to obtain volume data by performing ultrasonic scan in a three-dimensional region in real time. Accordingly, there are trade-offs between the volume rate and the depth of field/azimuth resolution (the number of beams of azimuth/elevation). For this reason, there is a problem that sufficient volume rate and azimuth resolution are not obtained, compared with two-dimensional imaging in real time.

[0007] In order to solve such a problem, for example, JP-A-2007-215630 discloses a technique of generating a four-dimensional image corresponding to the entire scan range by acquiring data of one cardiac beat in each of different scan ranges by changing the scan start position in a three-dimensional scan range on the basis of an electrocardiographic signal using a two-dimensional array probe, in which ultrasonic vibrators are arrayed in a two-dimensional matrix, and then combining data of the same time phase later. In addition, there is a technique of improving the volume rate by obtaining received beams corresponding to several times the transmitted beams using parallel and simultaneous reception or a technique in which these techniques are combined.

[0008] However, there are following problems in the techniques for obtaining the sufficient volume rate and azimuth resolution in real-time display of a three-dimensional image.

[0009] First, in the case of using an electrocardiographic signal, a time of a plurality of cardiac beats is required in order to collect volume data. Moreover, in practice, full volume data is generated by connecting a plurality of subvolumes collected corresponding to different cardiac beats. For this reason, since time delay occurs, real-time display is not realized properly.

[0010] In addition, in the case of using parallel and simultaneous reception, the volume rate is increased as the number of parallel stages is increased. However, it is necessary to increase the transmission energy in order to cover a wide range of the receiving area. For this reason, a problem of power/generation of heat occurs, and received beams become heterogeneous due to influences of the sound field distribution of transmitted beams. As a result, the quality of an image may be degraded.

BRIEF SUMMARY OF THE INVENTION

[0011] In view of the above, it is an object of the present invention to provide an ultrasonic diagnostic apparatus and an ultrasonic image acquisition method capable of solving heterogeneousness of received beams by reducing time delay and power required for transmission of an ultrasonic wave, compared with those in the related art, in real-time display of a three-dimensional ultrasonic image.

[0012] According to an aspect of the present invention, there is provided an ultrasonic diagnostic apparatus including: a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body; a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputs a first signal; a signal processing unit that performs frequency demodulation of the first signal and generates a second echo signal separated for every position within the predetermined region; a data generating unit that generates first volume data using the second signal; and an image generating unit that generates an ultrasonic image using the first volume data.

[0013] According to another aspect of the present invention, there is provided an ultrasonic diagnostic apparatus including: a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body; a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputs a first signal; a signal processing unit that performs frequency demodulation of the first signal for every range in a multi-phase demodulation method and generates a second echo signal separated for every position within the predetermined region; a data generating unit that generates first volume data using the second signal; and an image generating unit that generates an ultrasonic image using the first volume data.

[0014] According to yet another aspect of the present invention, there is provided an ultrasonic diagnostic apparatustus including: a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body; a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region using a first reception delay time regarding a reference beam and a plurality of second delay times determined for every beam as correction delay times for the first reception delay time and that outputs a first signal; a signal processing unit that performs frequency demodulation of the first signal and generates a second echo signal separated for every position within the predetermined region; a data generating unit that generates first volume data using the second signal; and an image generating unit that generates an ultrasonic image using the first volume data.

[0015] According to yet another aspect of the present invention, there is provided an ultrasonic diagnostic apparatus including: a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body; a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputs a first signal; a signal processing unit that sequentially extracts the first signals, of which frequency bands are different, by performing filtering processing in a time-shared way using a variable band pass filter after performing frequency demodulation of the first signal and generates a second echo signal separated for every position within the predetermined region by executing discrete Fourier transform of the extracted first signals, of which frequency bands are different, in a time-shared way; a data generating unit that generates first volume data using the second signal; and an image generating unit that generates an ultrasonic image using the first volume data.

[0016] According to yet another aspect of the present invention, there is provided an ultrasonic image acquisition method including: transmitting a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body; performing multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputting a first signal; performing frequency demodulation of the first signal and generating a second echo signal separated for every position within the predetermined region; generating first volume data using the second signal; and generating an ultrasonic image using the first volume data.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0017] FIG. **1** is a block diagram illustrating the configuration of an ultrasonic diagnostic apparatus according to the present embodiment;

[0018] FIG. **2** is a view for explaining the configuration of an ultrasonic probe provided in the ultrasonic diagnostic apparatus;

[0019] FIG. **3** is a view for explaining the configuration of a transmission and reception unit;

[0020] FIG. **4** is a flow chart illustrating the flow of process (real-time display process of a three-dimensional image) based on the function of real-time display of a three-dimensional image;

[0021] FIG. **5** is a view illustrating the concept of transmission using a frequency modulation method and multi-beam reception for every range using a frequency demodulation method;

[0022] FIG. **6** is a view for explaining processing for detecting a fundamental wave component from a beam for every range received using the frequency demodulation method;

[0023] FIG. **7** is a view for explaining processing for detecting a fundamental wave component from a beam for every range received using the frequency demodulation method;

[0024] FIG. **8** is a view illustrating the hardware configuration regarding reception of a transmission and reception unit of an ultrasonic diagnostic apparatus in the first modification;

[0025] FIG. **9** is a view illustrating the hardware configuration regarding reception of the transmission and reception unit of the ultrasonic diagnostic apparatus;

[0026] FIG. **10** is a view for explaining frequency demodulation processing in the ultrasonic diagnostic apparatus in the first modification;

[0027] FIG. **11** is a view illustrating the hardware configuration regarding reception of a transmission and reception unit of an ultrasonic diagnostic apparatus in the second modification;

[0028] FIG. **12** is a view for explaining frequency demodulation processing in the ultrasonic diagnostic apparatus in the second modification;

[0029] FIG. **13** is a view illustrating the analog configuration of a DFT in the second modification;

[0030] FIG. **14**A is a view for explaining a delay method of the ultrasonic diagnostic apparatus in this modification, and FIG. **14**B is a view illustrating a delay method in known beam forming; and

[0031] FIG. **15** is a view for explaining a phase delay method using a matrix switch.

DETAILED DESCRIPTION OF THE INVENTION

[0032] Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings. Moreover, in the following description, components having approximately the same function and configuration are denoted by the same reference numeral, and a repeated explanation thereof will only be made when necessary.

[0033] FIG. **1** is a block diagram illustrating the configuration of an ultrasonic diagnostic apparatus **11** according to the present embodiment. As shown in FIG. **1**, the ultrasonic diagnostic apparatus **11** includes an ultrasonic probe **12**, an input device **13**, a monitor **14**, an ultrasonic wave transmission and reception unit **22**, a B-mode processing unit **23**, a Doppler processing unit **24**, an image generating unit **25**, a volume data generating unit **26**, an image mixing unit **27**, a control processor (CPU) **28**, an internal storage unit **31**, and an interface unit **33**. Hereinafter, a function of each constituent component of the ultrasonic diagnostic apparatus **11** will be described.

[0034] The ultrasonic probe **12** generates an ultrasonic wave on the basis of a driving signal from the ultrasonic wave transmission and reception unit **22** and has a plurality of piezoelectric vibrators that convert a reflected wave from a subject body into an electric signal, a matching layer provided in the piezoelectric vibrators, a backing material for preventing propagation of an ultrasonic wave rearward from the piezoelectric vibrators, and the like. When an ultrasonic wave is transmitted from the ultrasonic probe **12** to a subject body

P, the transmitted ultrasonic wave is sequentially reflected on a discontinuous surface of acoustic impedances of body tissues and is then received as an echo signal by the ultrasonic probe **12**. The amplitude of the echo signal depends on the difference of the acoustic impedances on the discontinuous surfaces on which the ultrasonic wave is reflected. In addition, an echo when transmitted ultrasonic pulses are reflected by a moving blood flow, on surface of a heart wall, and the like is frequency-shifted depending on a speed component of the moving body in the ultrasonic wave transmission direction by the Doppler effect.

[0035] In addition, the ultrasonic probe **12** provided in the ultrasonic diagnostic apparatus is a two-dimensional-array probe in which a plurality of ultrasonic vibrators are arrayed in a two-dimensional matrix. Moreover, the ultrasonic probe **12** has a transmission area (Tx Area) and a receiving area (Rx Area), each of which is configured to include a plurality of ultrasonic vibrators, in order to execute transmission and reception of a continuous ultrasonic wave in parallel. A frequency-modulated continuous ultrasonic wave is transmitted in the transmission area, and multi-beam reception is executed while performing frequency demodulation in the receiving area. This will be described in detail later.

[0036] The input device **13** is connected to an apparatus body **11** and has various switches, buttons, a track ball, a mouse, a keyboard, and the like used to perform various instructions from an operator, an instruction for setting a condition or a region of interest (ROI), an instruction for setting various conditions of image quality, and the like on the apparatus body **11**. For example, when the operator operates a stop button or a 'FREEZE' button of the input device **13**, transmission and reception of an ultrasonic wave are stopped and the ultrasonic diagnostic apparatus is temporarily stopped.

[0037] The monitor **14** displays morphological information (a normal B-mode image) in the body, blood flow information (including an average speed image, a dispersion image, a power image), and the like in predetermined forms on the basis of a video signal from the scan converter **25**.

[0038] The ultrasonic wave transmission and reception unit **22** has a signal generator **220**, a transmission mixer **221**, a transmission delay unit **222**, an apodization unit **223**, a frequency modulation/demodulation unit **224**, a receiving buffer unit **226**, a receiving mixer **227**, a DBPF **228**, a discrete Fourier transform unit **229**, and a beam memory **230**, as shown in FIG. **3**. The ultrasonic wave transmission and reception unit **22** not only performs transmission and reception of an ultrasonic wave in a normal B mode, a pulse Doppler mode, or the like, but also performs multi-beam reception while performing frequency demodulation of a reflected wave obtained as a result of transmission of a frequency-modulated continuous ultrasonic wave in the case of executing real-time display of a three-dimensional image.

[0039] The B-mode processing unit **23** receives an echo signal from the transmission and reception unit **22**, performs logarithmic amplification, envelope detection processing, and the like, and generates data in which the signal strength is expressed as a brightness level. This data is transmitted to the scan converter **25** and is displayed on the monitor **14** as a B-mode image which expresses the strength of a reflected wave by the brightness.

[0040] The Doppler processing unit **24** performs a frequency analysis of speed information from the echo signal received from the transmission and reception unit **22**, extracts a blood flow or a tissue and a contrast echo component caused by the Doppler effect, and calculates blood flow information, such as an average speed, dispersion, and power, for multiple points. In particular, the Doppler processing unit **24** reads multi-phase demodulated data sequentially from the transmission and reception unit **22**, calculates the spectrum obtained in each range, and calculates data of a CW spectrum image using the spectrum.

[0041] The image generating unit **25** generates an ultrasonic image using the data received from the B-mode processing unit **23**, the Doppler processing unit **24**, and the volume data generating unit **26**.

[0042] The volume data generating unit **26** generates volume data corresponding to each time phase by connecting subvolume data using a function of real-time display of a three-dimensional image, which will be described later.

[0043] The image mixing unit **27** mixes an image received from the image generating unit **25** with alphabetic information, scales, or the like of various parameters and outputs the mixing result as a video signal to the monitor **14**.

[0044] The control processor **28** has a function as an information processing device (computer) and controls an operation of the main body of the ultrasonic diagnostic apparatus. The control processor **28** reads an exclusive program for realizing a function of real-time display of a three-dimensional image, which will be described later, and a control program for executing a predetermined scan sequence from the internal storage unit **31**, loads the read programs onto its own memory, and executes an operation, control, and the like regarding various kinds of processing.

[0045] The internal storage unit **31** stores a predetermined scan sequence for collecting a plurality of volume data by the setting of different angles of view, an exclusive program for realizing a function of real-time display of a three-dimensional image which will be described later, a control program for executing image generation and display processing, diagnostic information (for example, a patient ID or doctor's opinion), a diagnostic protocol, transmission and reception conditions, a body mark creating program, and other data groups. In addition, the internal storage unit **31** may be used to store an image in the image memory **26** as necessary. Data stored in the internal storage unit **31** may be transmitted to an external peripheral device through the interface unit **33**.

[0046] The interface unit **33** is an interface related to the input device **13**, a network, and a new external storage device (not shown). Data, an analysis result, or the like of an ultrasonic image and the like obtained by the apparatus may be transmitted to another apparatus through the network by the interface unit **33**.

[0047] (Function of Real-Time Display of a Three-Dimensional Image)

[0048] Next, a function of real-time display of a three-dimensional image that the ultrasonic diagnostic apparatus **11** has will be described. This function is to perform real-time display of a three-dimensional ultrasonic image in which there is little time delay, power required for transmission of an ultrasonic wave is reduced, and heterogeneousness of received beams is almost solved by performing multi-beam reception while performing frequency demodulation of a reflected wave obtained as a result of transmission of a frequency-modulated continuous ultrasonic wave to the subject body. Moreover, in the present embodiment, a multi-phase demodulation method is adopted as a demodulation method in order to make a specific explanation. This is to obtain the distance resolution in multi-beam reception by performing (multi-phase) demodulation while changing the phases of transmission modulation and reception modulation for every range in the range direction (beam direction). However, the technical spirit of the present invention is not limited to the multi-phase demodulation method, but any demodulation method may be adopted as long as the substantially same result as in the multi-phase demodulation method can be acquired.

[0049] FIG. **4** is a flow chart illustrating the flow of process (real-time display process of a three-dimensional image) based on the function of real-time display of a three-dimensional image. Hereinafter, the real-time display process of a three-dimensional image will be described according to the flow chart.

[0050] [Continuous Ultrasonic Wave Transmission Using a Frequency Modulation Method: Step S**1**]

[0051] First, transmission of a continuous ultrasonic wave, the transmission voltage for which is low (power/generation of heat is small), is executed using the frequency modulation method (step S**1**). That is, the signal generator **220** performs frequency modulation using the frequency modulation/demodulation unit **224**. In addition, a transmission delay time is given to the frequency-modulated signal by the transmission delay unit **222** and beam directivity is given to the frequency-modulated signal by the apodization unit **223**, and then the frequency-modulated signal is supplied to the ultrasonic probe **12**. This supply is executed in a sequential manner. The ultrasonic probe **12** transmits the continuous ultrasonic wave (continuous wave chirp) into the subject body on the basis of the supplied signal.

[0052] In addition, in order to realize ultrasonic scan in a wide range, it is preferable that the continuous ultrasonic wave be transmitted in the shape of a fan beam. In addition, in order to prevent the electric power from concentrating on one element, it is preferable that the continuous ultrasonic wave of a fan beam be transmitted while changing the direction.

[0053] [Multi-Beam Reception Using a Frequency Demodulation Method: Step S**2**]

[0054] Next, multi-beam reception using a frequency demodulation method is executed (step S**2**). That is, the ultrasonic probe **12** performs multi-beam reception of a reflected wave from the inside of the subject body based on the transmitted continuous ultrasonic wave for every range direction. The receiving buffer unit **226** performs A/D conversion of each of beams which were received as multiple beams in a buffer circuit provided corresponding to each range and stores it as digital data first. In addition, since the receiving buffer unit **226** functions as a buffer connected with time delay, sample data of multi-phases corresponding to the resolving power in the range direction is mapped as much as the Nfm period of FM modulation by related storage. The receiving mixer **227** and the frequency modulation/demodulation unit **224** execute multi-phase FM demodulation in synchronization with transmission modulation for every range direction. Here, 'synchronization' means performing FM demodulation with a chirp wave synchronized with a chirp wave for frequency modulation with respect to a transmitted continuous wave with a fixed time interval therebetween. Moreover, as a measure against saturation of an echo signal from the short distance when performing reception in this step, it is preferable to perform a TGC (time gain control) according to a modulation period frequency.

[0055] By such a multi-phase FM demodulation method, as shown in FIG. **5**, reflected waves based on continuous ultrasonic waves transmitted using a frequency modulation method are received such that the phase of transmission modulation and the phase of reception modulation are changed for every range and the reflected waves are synchronized with a fixed time interval therebetween.

[0056] [Discrete Fourier Transform: Step S**3**]

[0057] Next, discrete Fourier transform is executed for each of beams received as multiple beams by using a frequency demodulation method, and a fundamental wave for every range is extracted (step S**3**). That is, the discrete Fourier transform unit **229** executes discrete Fourier transform for each beam in each range filtered by the band filter unit **228** and calculates the spectrum of each beam in each range as shown in FIG. **6** (step S**3**). The beam memory **230** rearranges the calculated spectrum of fundamental wave components of each beam with a range as a reference as shown in FIG. **7** and then acquires fundamental wave power (that is, A-mode information for every range) for every range as it is shown in FIG. **8**. As a result, an echo signal is extracted for every distance.

[0058] [Generation of Volume Data: Step S**4**]

[0059] Next, processing of steps S**1** to S**3** is executed sequentially and continuously, such that subvolume data for a predetermined region is sequentially generated. Moreover, if necessary, received signal gain correction processing for correcting the sensitivity difference within the subvolume and the sensitivity difference between subvolumes caused by interpolation processing and the like is executed. Moreover, if necessary, in order to improve the S/N ratio, a modulated wave may be applied for subvolume data a plural number of times so that the subvolume data is temporally mixed. The volume data generating unit **26** generates volume data by aligning and connecting the subvolumes obtained in this way (step S**4**).

[0060] [Generation/Display of a Three-Dimensional Image: Step S**5**]

[0061] Next, the image generating unit **25** generates a three-dimensional image using the generated volume data (step S**5**). The generated three-dimensional image is mixed with required information in the image mixing unit **27** and is then displayed on the monitor **14** in a predetermined form (step S**5**).

[0062] (First Modification)

[0063] Next, the first modification of the ultrasonic diagnostic apparatus **11** according to the present embodiment will be described. The ultrasonic diagnostic apparatus **11** in the first modification is an example in which the entire hardware size is reduced particularly by integrating circuits related to reception.

[0064] FIG. **9** is a view illustrating the hardware configuration regarding reception of the transmission and reception unit **22** of the ultrasonic diagnostic apparatus **11**. As shown in FIG. **9**, echo signals received by a plurality of ultrasonic vibrators are A/D converted in the buffer unit **232**, are stored as digital data first, and are transmitted to the receiving mixer **227** corresponding to each range. A phase shift circuit **233** controls the operation timing of the receiving mixer **227** on the basis of a control signal from the frequency modulation/demodulation unit **224**, and executes multi-phase FM demodulation in synchronization with transmission modulation for every range direction as shown in FIG. **10**. A fundamental wave calculation circuit **235** corresponding to each range calculates the amplitude of a fundamental wave for every range using each beam for every range filtered by a LPF (low pass filter) **234**.

[0065] According to the above configuration, the hardware size can be reduced, and the multi-beam reception can be performed while performing multi-phase demodulation of a reflected wave obtained as a result of transmission of a frequency-modulated continuous ultrasonic wave to the subject body.

[0066] (Second Modification)

[0067] Next, the second modification of the ultrasonic diagnostic apparatus **11** according to the present embodiment will be described. The ultrasonic diagnostic apparatus **11** in the second modification is an example in which the hardware size related to reception is reduced by narrowing components to be detected to clutter components (that is, by making Doppler components not included).

[0068] FIG. **11** is a view illustrating the hardware configuration regarding reception of the transmission and reception unit **22** of the ultrasonic diagnostic apparatus **11**. In this modification, components to be detected are narrowed to clutter components. Accordingly, by using a variable BPF (band pass filter) **236** and a DFT **229** in a time-shared way as shown in FIG. **11**, signal processing for a plurality of ranges can be performed in one system. That is, the variable BPF **236** performs frequency demodulation of a received fundamental frequency Freq. as shown in FIG. **12** while executing filtering for making a signal, which corresponds to a band having a width of Δf from the received fundamental frequency Freq., pass the variable BPF **236** according to the control from frequency modulation/demodulation unit **224**. The DFT **229** calculates the amplitude of a clutter component for every range using each beam for every range filtered in the variable BPF **236**. In this case, it is preferable to calculate the total power of beams corresponding to each range. In addition, the DFT **229** may be replaced with an analog configuration shown in FIG. **13**.

[0069] Also by the above configuration, the hardware size can be reduced, and a clutter component can be detected by performing multi-beam reception while performing multi-phase demodulation of a reflected wave obtained as a result of transmission of a frequency-modulated continuous ultrasonic wave to the subject body.

[0070] (Third Modification)

[0071] Next, the third modification of the ultrasonic diagnostic apparatus **11** according to the present embodiment will be described. In the case of the ultrasonic diagnostic apparatus **11** in the third modification, the hardware size is reduced by configuring a delay method when performing multi-beam reception with delay of a center beam and correction delay of a peripheral beam. That is, it is another method for realizing apodization data or delay data of reception apodization and reception delay unit of a beam former of parallel and simultaneous reception shown in FIG. **3**.

[0072] FIG. **14**A is a view for explaining a delay method of the ultrasonic diagnostic apparatus **11** in this modification, and FIG. **14**B is a view illustrating a delay method in known beam forming. As shown in FIG. **14**B, in the known delay method, deflection delay and convergence delay are defined for every beam corresponding to each range independently. On the other hand, in this modification, as shown in FIG. **14**A, deflection delay and convergence delay regarding the center beam are defined and deflection delay and convergence delay for every beam corresponding to each range are defined as amounts of deviation therefrom. In addition, deflection delay and convergence delay for every beam corresponding to each range with the center beam as a reference are stored beforehand in the internal storage unit **31** for various conditions, for example.

[0073] In addition, when performing the above-described beam delay, it is preferable to realize phase delay using a matrix switch (multi-input multi-output switch) shown in FIG. **15**. According to such a configuration, the performance can be significantly improved compared with pulse phase delay. In addition, the matrix switch is a multi-input multi-output switch by which delay signals corresponding to delay values can be programmably switching-input to a plurality of beam sum inputs.

[0074] (Effects)

[0075] According to the ultrasonic diagnostic apparatus of the present embodiment, multi-beam reception is performed while performing frequency demodulation of a reflected wave obtained as a result of transmission of a continuous ultrasonic wave, the transmission voltage for which is low, by using the frequency demodulation method. Accordingly, generation of heat caused by transmission power can be suppressed. In addition, discrete Fourier transform and the like are executed for each of beams received as multiple beams using the frequency demodulation method, an echo signal for every distance corresponding to each range is detected, and a three-dimensional image is displayed in real time using it. Accordingly, since an echo signal having distance resolution can be acquired by scanning an ultrasonic wave in a wide range, a three-dimensional image can be generated and displayed in real time without requiring the time of a plurality of cardiac beats.

[0076] In addition, the present invention is not limited to the above-described embodiment and may be embodied in practice by modifying constituent components without departing from the scope and spirit of the present invention. For example, specific modifications include the following examples.

[0077] (1) Each of the functions in the present embodiment may be realized by installing a program for executing corresponding processing in a computer, such as a workstation, and then loading the program into the memory. In this case, a program capable of causing a computer to execute a corresponding technique may be distributed in a state where the program is stored in a recording medium, such as a magnetic disk (for example, a floppy (registered trademark) disk or a hard disk), an optical disk (for example, a CD-ROM or a DVD), and a semiconductor memory.

[0078] (2) In the above-described embodiment, Doppler information may be acquired and displayed by performing triangular wave modulation, for example, without performing saw-tooth wave modulation shown in FIG. **5** and the like. In addition, the saw-tooth wave may be transmitted and received intermittently according to the required depth of field. In addition, a modulated wave may be made to have a curve to increase the short-distance resolution.

[0079] (3) In the above-described embodiment, when calculating A-mode information from a received beam, DC component power may be calculated only by a digital mixer. The hardware size can be further reduced by adopting the above-described configuration. In addition, calculating A-mode information from a received beam may also be realized by using an LPF which extracts only a DC component after an analog mixer.

[0080] (4) In the above-described embodiment, the case in which the technical spirit of the present invention was applied to the ultrasonic diagnostic apparatus as a function of real-time display of a three-dimensional image was exemplified. However, the technical spirit of the present invention is not limited to the example of application to the ultrasonic diagnostic apparatus. For example, the technical spirit of the present invention may also be applied to an apparatus which gives the alarm for preventing collision of a moving object (for example, an automobile) using an ultrasonic wave. In this case, not only an ultrasonic image but also a sound or the like which warns the possibility of collision may be output as information supplied to the operator in real time.

[0081] In addition, various kinds of inventions may be realized by proper combination of the plurality of constituent components disclosed in the embodiment described above. For example, some constituent components may be eliminated from all components shown in the above embodiment. Moreover, the constituent components in different embodiments may be appropriately combined.

What is claimed is:

1. An ultrasonic diagnostic apparatus comprising:
- a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body;
- a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputs a first signal;
- a signal processing unit that performs frequency demodulation of the first signal and generates a second echo signal separated for every position within the predetermined region;
- a data generating unit that generates first volume data using the second signal; and
- an image generating unit that generates an ultrasonic image using the first volume data.

2. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the transmission unit transmits the continuous ultrasonic wave into the predetermined region in the shape of a fan beam.

3. The ultrasonic diagnostic apparatus according to claim **2**,
- wherein the transmission unit transmits the continuous ultrasonic wave to each of a plurality of subregions, which forms the predetermined region, by switching of transmission direction of the fan beam.

4. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the transmission unit transmits the continuous ultrasonic wave to each of a plurality of subregions, which forms the predetermined region, a plural number of times, and
- the reception unit outputs the temporally mixed first signal using the continuous reflected wave corresponding to each of the plural number of transmissions.

5. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the frequency modulation is saw-tooth modulation.

6. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the frequency modulation is triangular wave modulation.

7. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the frequency modulation is curve wave modulation.

8. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the transmission unit uses saw-tooth modulation intermittently according to depth of field.

9. The ultrasonic diagnostic apparatus according to claim **3**,
- wherein the reception unit performs multi-beam reception of the continuous reflected wave for each of the subregions and outputs the first signal corresponding to each subregion,
- the signal processing unit performs frequency demodulation of the first echo signal corresponding to each subregion and generates the second signal corresponding to each subregion, and
- the data generating unit generates the first volume data using the second signal for each of the subregions.

10. The ultrasonic diagnostic apparatus according to claim **9**,
- wherein the signal processing unit corrects a sensitivity difference between the first echo signals corresponding to the respective subregions.

11. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the signal processing unit performs frequency demodulation of the first signal for every range using a multi-phase demodulation method.

12. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the signal processing unit executes discrete Fourier transform after performing frequency demodulation of the first signal and generates the second signal including amplitude information using the first signal after the discrete Fourier transform.

13. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the signal processing unit extracts a fundamental wave component from the first signal using a digital mixer and generates the second signal including amplitude information on the basis of the extracted fundamental wave component.

14. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the signal processing unit extracts a fundamental wave component from the first signal using a low pass filter after processing using an analog mixer and generates the second signal including amplitude information on the basis of the extracted fundamental wave component.

15. The ultrasonic diagnostic apparatus according to claim **1**,
- wherein the signal processing unit sequentially extracts the first signals, of which frequency bands are different, by performing filtering processing in a time-shared way using a variable band pass filter after performing frequency demodulation of the first signal and generates the second signal by executing discrete Fourier transform of the extracted first signals, of which frequency bands are different, in a time-shared way.

16. The ultrasonic diagnostic apparatus according to claim **1**,

wherein the signal processing unit executes a time gain control in synchronization with the frequency demodulation.

17. The ultrasonic diagnostic apparatus according to claim **1**,

wherein the reception unit executes the multi-beam reception using a first reception delay time regarding a reference beam of the multiple beams and a plurality of second delay times determined for every beam as correction delay times for the first reception delay time.

18. The ultrasonic diagnostic apparatus according to claim **17**,

wherein the reception unit executes multi-beam reception using the first reception delay time and the plurality of second reception delay times by using matrix switching.

19. An ultrasonic diagnostic apparatus comprising:

a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body;

a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputs a first signal;

a signal processing unit that performs frequency demodulation of the first signal for every range in a multi-phase demodulation method and generates a second echo signal separated for every position within the predetermined region;

a data generating unit that generates first volume data using the second signal; and

an image generating unit that generates an ultrasonic image using the first volume data.

20. An ultrasonic diagnostic apparatus comprising:

a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body;

a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region using a first reception delay time regarding a reference beam and a plurality of second delay times determined for every beam as correction delay times for the first reception delay time and that outputs a first signal;

a signal processing unit that performs frequency demodulation of the first signal and generates a second echo signal separated for every position within the predetermined region;

a data generating unit that generates first volume data using the second signal; and

an image generating unit that generates an ultrasonic image using the first volume data.

21. An ultrasonic diagnostic apparatus comprising:

a transmission unit that transmits a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body;

a reception unit that performs multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputs a first signal;

a signal processing unit that sequentially extracts the first signals, of which frequency bands are different, by performing filtering processing in a time-shared way using a variable band pass filter after performing frequency demodulation of the first signal and generates a second echo signal separated for every position within the predetermined region by executing discrete Fourier transform of the extracted first signals, of which frequency bands are different, in a time-shared way;

a data generating unit that generates first volume data using the second signal; and

an image generating unit that generates an ultrasonic image using the first volume data.

22. An ultrasonic image acquisition method comprising:

transmitting a frequency-modulated continuous ultrasonic wave to a predetermined region of a subject body;

performing multi-beam reception of a continuous reflected wave generated on the basis of the continuous ultrasonic wave from the predetermined region and outputting a first signal;

performing frequency demodulation of the first signal and generating a second echo signal separated for every position within the predetermined region;

generating first volume data using the second signal; and

generating an ultrasonic image using the first volume data.

* * * * *

专利名称(译)	超声波诊断装置和超声波图像采集方法		
公开(公告)号	US20100010350A1	公开(公告)日	2010-01-14
申请号	US12/501736	申请日	2009-07-13
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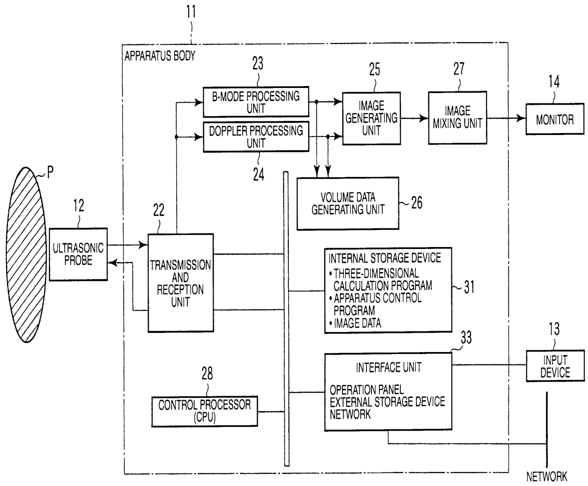
IPC分类号	A61B8/14		
CPC分类号	A61B8/483 G01S7/5203 G01S7/52095 G01S15/8993 G01S15/8954 G01S15/8979 G01S15/8927		
优先权	2008183137 2008-07-14 JP 2009157067 2009-07-01 JP		
外部链接	Espacenet USPTO		

摘要(译)

实时显示三维超声波图像，其中几乎没有时间延迟，传输超声波所需的功率减少，并且通过在执行频率解调的同时执行多波束接收来执行接收波束的异质性。由于频率调制的连续超声波传输到对象身体而获得的反射波的波长。作为解调方法，例如，通过在改变范围方向上的每个范围的发送调制和接收调制的相位的同时执行（多相）解调来获得多波束接收中的距离分辨率的多相解调方法（光束方向）。



11
APPARATUS BODY
23
B-MODE PROCESSING UNIT
25
IMAGE GENERATING UNIT
27
IMAGE MIXING UNIT
14
MONITOR
DOPPLER PROCESSING UNIT
24
P
12
ULTRASONIC PROBE
22
TRANSMISSION AND RECEPTION UNIT
VOLUME DATA GENERATING UNIT
26
INTERNAL STORAGE DEVICE
• THREE-DIMENSIONAL CALCULATION PROGRAM
• APPARATUS CONTROL PROGRAM
• IMAGE DATA
31
33
13
INTERFACE UNIT
OPERATION PANEL
EXTERNAL STORAGE DEVICE
NETWORK
INPUT DEVICE
28
CONTROL PROCESSOR (CPU)
NETWORK