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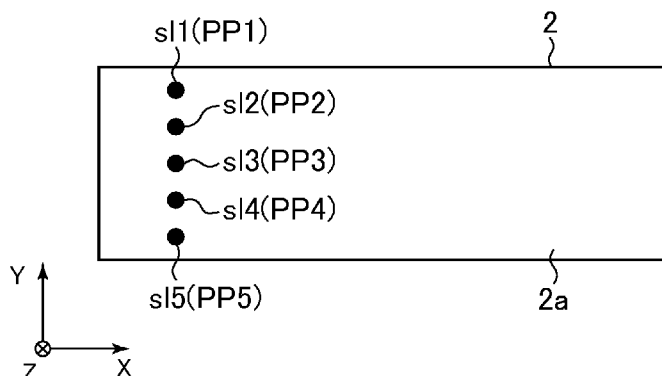
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(54) Title: ULTRASONIC DIAGNOSTIC APPARATUS, AND PROGRAM

FIG.6



(57) Abstract: [Problem] To provide an ultrasonic diagnostic apparatus capable of providing an elasticity image more correctly reflecting the elasticity of biological tissue than by conventional techniques. [Means for Solution] An ultrasonic diagnostic apparatus is characterized in comprising: an ultrasonic probe 2 for performing transmission/reception of ultrasound; and a transmission control section for transmitting an ultrasonic push pulse PP1—PP5 from the ultrasonic probe 2 along each of a plurality of different acoustic lines s11 - s15 arranged side by side in one direction, the transmission control section transmitting a plurality of the ultrasonic push pulses PP1—PP5 to biological tissue in time with when each of shear waves generated in the biological tissue by each respective one of the plurality of push pulses PP1—PP5 is combined together.



ULTRASONIC DIAGNOSTIC APPARATUS, AND PROGRAM

FIELD OF THE INVENTION

[001] The present invention relates to an ultrasonic diagnostic apparatus and a program for transmitting ultrasonic push pulses to measure the elasticity of biological tissue.

BACKGROUND

[002] There have been known elasticity measurement techniques of measuring the elasticity of biological tissue by transmitting ultrasonic pulses (push pulses) having a high acoustic pressure from an ultrasonic probe to the biological tissue (for example, see Patent Document 1). According to the elasticity measurement techniques, a shear wave generated in the biological tissue by a push pulse is detected by ultrasonic detecting pulses, and the velocity of propagation of the shear wave and/or the elasticity value of the biological tissue are calculated to provide elasticity data.

SUMMARY OF THE INVENTION

[003] The shear wave is a transverse wave propagating in a direction (lateral direction) intersecting the direction of transmission of the push pulse. Since the shear wave propagates through biological tissue while cylindrically diffusing around the push pulse, the amplitude of the shear wave sharply attenuates as it goes farther away from the push pulse. As such, elasticity data obtained based on the shear wave detected at a position away from the push pulse may incorrectly reflect the elasticity of the biological tissue. Therefore, there has been a problem that, to obtain elasticity data correctly reflecting the elasticity of biological tissue, attenuation of a shear wave should be suppressed at a position away from a push pulse.

MEANS FOR SOLVING THE PROBLEM

[004] The invention in one aspect made for solving the problem described above is an ultrasonic diagnostic apparatus, characterized in comprising: an ultrasonic probe for performing transmission/reception of ultrasound; and a transmission control section for transmitting an ultrasonic push pulse from said ultrasonic probe along each of a plurality of different acoustic lines arranged side by side in one direction, said transmission control section transmitting a plurality of said ultrasonic push pulses to biological tissue in time with when each of shear waves generated in said biological tissue by each respective one of said plurality of push pulses is combined together.

[005] According to the invention in the aspect described above, once the push pulse has been transmitted to biological tissue along each of a plurality of different acoustic lines arranged side by

side in one direction, a shear wave generated in the biological tissue by each of a plurality of the push pulses is combined together to form a plane wave propagating through the biological tissue. Therefore, attenuation of a shear wave at a position away from the push pulse may be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] [FIG. 1] A block diagram showing a schematic configuration of an ultrasonic diagnostic apparatus that is an exemplary embodiment of the present invention.

[0007] [FIG. 2] A block diagram showing a configuration of an echo data processing section.

[0008] [FIG. 3] A block diagram showing a configuration of a display processing section.

[0009] [FIG. 4] A diagram showing a display section in which a B-mode image and an elasticity image are displayed.

[0010] [FIG. 5] A diagram explaining transmission of a push pulse.

[0011] [FIG. 6] A diagram explaining push pulses transmitted along acoustic lines lying at different positions.

[0012] [FIG. 7] A diagram explaining push pulses transmitted along acoustic lines lying at different positions.

[0013] [FIG. 8] A diagram explaining diffusion of shear waves.

[0014] [FIG. 9] A diagram explaining diffusion of shear waves.

[0015] [FIG. 10] A diagram explaining propagation of combined shear waves.

[0016] [FIG. 11] A diagram explaining transmission/reception of ultrasonic detecting pulses.

[0017] [FIG. 12] A diagram explaining transmission of push pulses in a 2D-array ultrasonic probe.

[0018] Now an embodiment of the present invention will be described based on the accompanying drawings. An ultrasonic diagnostic apparatus 1 shown in FIG. 1 comprises an ultrasonic probe 2, a transmission/reception (T/R) beamformer 3, an echo data processing section 4, a display processing section 5, a display section 6, an operating section 7, a control section 8, and a storage section 9. The ultrasonic diagnostic apparatus 1 has a configuration as computer.

[0019] The ultrasonic probe 2 represents an exemplary embodiment of the ultrasonic probe in the present invention, which transmits ultrasound to biological tissue in a subject. The ultrasonic probe 2 has a plurality of ultrasonic vibrators (not shown) arranged in an azimuthal direction. For example, the ultrasonic probe 2 is a 1.75D-array ultrasonic probe in which the plurality of ultrasonic

vibrators are divided also in an elevational direction orthogonal to the azimuthal direction.

[0020] By the ultrasonic probe 2, an ultrasonic pulse (push pulse) for generating a shear wave in the biological tissue is transmitted. Also by the ultrasonic probe 2, ultrasonic detecting pulses for detecting the shear wave are transmitted and echo signals thereof are received.

[0021] Moreover, by the ultrasonic probe 2, ultrasonic imaging pulses for producing a B-mode image may be transmitted and echo signals thereof may be received.

[0022] The T/R beamformer 3 drives the ultrasonic probe 2 based on control signals from the control section 8 to transmit the several kinds of ultrasonic pulses described above with predetermined transmission parameters (transmission control function). The T/R beamformer 3 and control section 8 represent an exemplary embodiment of the transmission control section in the present invention. The transmission control function represents an exemplary embodiment of the transmission control function in the present invention.

[0023] The T/R beamformer 3 also applies signal processing such as phased addition processing to ultrasonic echo signals.

[0024] The echo data processing section 4 comprises a B-mode processing section 41, a velocity-of-propagation calculating section 42, and an elasticity-value calculating section 43, as shown in FIG. 2. The B-mode processing section 41 applies B-mode processing such as logarithmic compression processing and envelope detection processing to echo data output from the T/R beamformer 3, and creates B-mode data.

[0025] The velocity-of-propagation calculating section 42 calculates a velocity of propagation of the shear wave based on echo data output from the T/R beamformer 3. The elasticity-value calculating section 43 calculates an elasticity value of the biological tissue to which a push pulse is transmitted based on the velocity of propagation. Details thereof will be discussed later. The velocity-of-propagation calculating section 42 and elasticity-value calculating section 43 represent an exemplary embodiment of the measurement-value calculating section in the present invention. The velocity of propagation and elasticity value represent an exemplary embodiment of the measurement value regarding the elasticity of biological tissue in the present invention.

[0026] It should be noted that only the velocity of propagation may be calculated without necessarily calculating the elasticity value. Data of the velocity of propagation or data of the elasticity value will be referred to herein as elasticity data.

[0027] The display processing section 5 comprises an image display processing section 51 and a

region defining section 52, as shown in FIG. 3. The image display processing section 51 scan-converts the B-mode data by a scan converter to create B-mode image data, based on which a B-mode image is displayed in the display section 6. The image display processing section 51 also scan-converts the elasticity data by the scan converter to create elasticity image data, based on which an elasticity image is displayed in the display section 6.

[0028] As shown in FIG. 4, the elasticity image EI is a two-dimensional image displayed within a region of interest R defined in the B-mode image BI. The elasticity image EI is a color image having colors according to the velocity of propagation or the elasticity value. The image display processing section 51 combines the B-mode image data and elasticity image data together to create combined image data, based on which an image is displayed in the display section 6. Therefore, the elasticity image EI is a semi-transparent image through which the B-mode image BI in the background is allowed to pass.

[0029] The region of interest R is defined by the region defining section 52. More specifically, the region defining section 52 defines the region of interest R based on an input by an operator at the operating section 7. The region of interest R is a region in which shear waves are to be detected, and transmission/reception of the ultrasonic detecting pulses is performed in this region. The region of interest R represents an exemplary embodiment of the two-dimensional region in the present invention.

[0030] The display section 6 is an LCD (Liquid Crystal Display), an organic EL (Electro-Luminescence) display, or the like. The display section 6 represents an exemplary embodiment of the display section in the present invention.

[0031] The operating section 7 is configured to comprise a keyboard for allowing an operator to input a command and/or information, a pointing device such as a trackball, and the like, although not particularly shown.

[0032] The control section 8 is a processor such as a CPU (Central Processing Unit). The control section 8 loads thereon a program stored in the storage section 9 and controls several sections in the ultrasonic diagnostic apparatus 1. For example, the control section 8 loads thereon a program stored in the storage section 9 and executes functions of the T/R beamformer 3, echo data processing section 4, and display processing section 5 by the loaded program.

[0033] The control section 8 may execute all of the functions of the T/R beamformer 3, all of the functions of the echo data processing section 4, and all of the functions of the display processing section 5 by the program, or execute only some of the functions by the program. In case that the

control section 8 executes only some of the functions, the remaining functions may be executed by hardware such as circuitry.

[0034] It should be noted that the functions of the T/R beamformer 3, echo data processing section 4, and display processing section 5 may be implemented by hardware such as circuitry.

[0035] The storage section 9 is an HDD (Hard Disk Drive), and/or a semiconductor memory such as a RAM (Random Access Memory) and/or a ROM (Read-Only Memory). The ultrasonic diagnostic apparatus 1 may have all of the HDD, RAM, and ROM as storage section 9. The storage section 9 may also be any portable storage medium such as a CD (Compact Disk) or a DVD (Digital Versatile Disk).

[0036] The program executed by the control section 8 is stored in a non-transitory storage medium such as the HDD or the ROM. The program may also be stored in any non-transitory portable storage medium such as the CD or the DVD.

[0037] Next, an operation of the ultrasonic diagnostic apparatus 1 in the present embodiment will be described. Here, production of an elasticity image will be described. Before an elasticity image is produced and displayed, the region of interest R may be defined by the operator in a B-mode image BI displayed in the display section 6.

[0038] Once the region of interest R has been defined, a push pulse PP is transmitted from the ultrasonic probe 2 to biological tissue T, as shown in FIG. 5. The push pulse PP is transmitted by the operator making an input at the operating section 7 for displaying an elasticity image, for example. The push pulse PP is transmitted to the vicinity of one edge of the region of interest R in a lateral direction (X direction) and in the outside of the region of interest R. However, the transmission position to which the push pulse PP is to be transmitted is not limited to the position shown in FIG. 5. For example, the push pulse PP may be transmitted to the inside of the region of interest R.

[0039] The push pulses PP are transmitted along a plurality of different acoustic lines sl1 -- sl5, as shown in FIGS. 6 and 7. A push pulse PP transmitted along the acoustic line sl1 is designated as push pulse PP1, that transmitted along the acoustic line sl2 as push pulse PP2, and that transmitted along the acoustic line sl3 as push pulse PP3. A push pulse PP transmitted along the acoustic line sl4 is designated as push pulse PP4, and that transmitted along the acoustic line sl5 as push pulse PP5.

[0040] Note that in FIG. 6, a transmission/reception plane 2a of the ultrasonic probe 2 is shown and an acoustic line is represented by a point. The plurality of acoustic lines sl1 -- sl5 are disposed in

one direction. In the present embodiment, the plurality of acoustic lines sl1 -- sl5 are disposed in an elevational direction (Y direction) of the ultrasonic probe 2. The elevational direction is a direction orthogonal to a direction of a plane for which an ultrasonic image is produced based on echo signals obtained by transmission/reception of ultrasound by the ultrasonic probe 2, i.e., to the azimuthal direction.

[0041] The push pulse PP generates a shear wave W in the biological tissue T by an acoustic radiation pressure. The shear wave W propagates through the biological tissue T while cylindrically diffusing around the push pulse, as shown in FIGS. 8 and 9. The T/R beamformer 3 intermittently and consecutively transmits the push pulses PP1 -- PP5 in sequence at intervals of the time at which a shear wave generated by each of the push pulses PP1 -- PP5 is combined together. After transmitting a push pulse along one acoustic line, the T/R beamformer 3 transmits a push pulse along another acoustic line adjacent to the one acoustic line before a shear wave generated by the previous push pulse reaches the another acoustic line. In this way, a shear wave generated by each of the push pulses along adjacent acoustic lines is combined together.

[0042] The intervals of time for transmitting the push pulses PP1 -- PP5 are defined beforehand. The intervals of time, however, may be modified by the operator at the operating section 7.

[0043] A shear wave generated from each of the push pulses intermittently and consecutively transmitted along a plurality of acoustic lines disposed in one direction is combined together to form a plane wave WW, as shown in FIG. 10. The plane wave WW propagates away from the push pulse PP through the biological tissue in the lateral direction.

[0044] It should be noted that part of the plane wave WW is shown in FIG. 10. The T/R beamformer 3 transmits ultrasonic detecting pulses DP for detecting shear waves in the form of the plane wave WW from the ultrasonic probe 2, as shown in FIG. 11. Then echo signals of the ultrasonic detecting pulses are received at the ultrasonic probe 2.

[0045] Transmission/reception of the ultrasonic detecting pulses DP is performed for a plurality of acoustic lines with respect to the region of interest R. While in FIG. 11, ultrasonic detecting pulses DP along a plurality of acoustic lines in the region of interest R are shown, transmission/reception of the ultrasonic detecting pulses DP is performed on an acoustic-line-by-acoustic-line basis. For example, transmission/reception of the ultrasonic detecting pulses DP may be performed sequentially from an acoustic line closer to the push pulse PP. The transmission/reception of the ultrasonic detecting pulses DP may be performed a plurality of times for each acoustic line.

[0046] Positions to which the ultrasonic detecting pulses DP are transmitted with respect to the

positions of the push pulses PP1 -- PP5 lie in a direction orthogonal to the direction of disposition of the acoustic lines sl1 -- sl5 along which the push pulses PP1 -- PP5 are transmitted, i.e., in the azimuthal direction.

[0047] After echo signals of the ultrasonic detecting pulses DP have been acquired, elasticity data is created based on the echo signals. The elasticity data is data of the velocity of propagation or of the elasticity value calculated based on the velocity of propagation for the shear waves W. More specifically, the velocity-of-propagation calculating section 42 calculates a velocity of propagation of the shear waves W detected in echo signals of the ultrasonic detecting pulses DP. The elasticity-value calculating section 43 calculates an elasticity value (Young's modulus (in Pa: Pascal)) based on the velocity of propagation of the shear waves W. However, only the velocity of propagation may be calculated without calculating the elasticity value.

[0048] The elasticity data is created for a plurality of portions in each of the acoustic lines along which the ultrasonic detecting pulses DP are transmitted/received. The plurality of portions correspond to pixels, for example.

[0049] Once the elasticity data has been created, elasticity image data is created based on the elasticity data, and an elasticity image EI based on the elasticity image data is displayed in the region of interest R (see FIG. 4).

[0050] Since according to the present embodiment, a shear wave generated by each of the push pulses PP1 -- PP5 transmitted along the plurality of different acoustic lines sl1 -- sl5 is combined together to form a plane wave, attenuation of a shear wave may be suppressed even at a position away from a push pulse. Since a shear wave may thus be detected with good S/N (signal to noise ratio) in echo signals of the ultrasonic detecting pulses DP even at a position away from a push pulse, elasticity data more correctly reflecting the elasticity of biological tissue can be obtained.

[0051] Moreover, since a plurality of push pulses are transmitted along different acoustic lines, the sound pressure of a push pulse transmitted along one acoustic line may be enhanced while complying with safety standards, in contrast with a case in which a plurality of push pulses are transmitted along one acoustic line. More specifically, for the same sound pressure of push pulses, the value of I_{spta} (spatial peak temporal average intensity), which is the highest time-averaged intensity of sound in a sound field, is different between a case in which a plurality of push pulses are transmitted along one acoustic line and a case in which they are transmitted along different acoustic lines. In particular, when a plurality of push pulses are transmitted along one acoustic line, I_{spta} in the acoustic line is calculated by time-integrating the plurality of push pulses. Therefore, the I_{spta}

value when a plurality of push pulses are transmitted along one acoustic line is higher than that when each of a plurality of push pulses is transmitted along a different acoustic line. As such, from the Ispta viewpoint, the sound pressure of one push pulse may be higher when each of a plurality of push pulses is transmitted along a different acoustic line than when a plurality of push pulses are transmitted along one acoustic line.

[0052] Since the sound pressure of each of a plurality of push pulses can thus be enhanced, it is possible to generate shear waves with greater amplitude.

[0053] While the present invention has been described with reference to the embodiments, it will be easily recognized that the present invention may be practiced with several modifications without departing from the spirit and scope thereof. For example, the ultrasonic probe 2 may be a 2D-array ultrasonic probe shown in FIG. 12. In this case, assuming that a plane for which an ultrasonic image is to be produced is in the azimuthal direction (X direction), a plurality of acoustic lines sl1 -- sl13 along which push pulses PP1 -- PP13 are to be transmitted are arranged side by side in the elevational direction (Y direction) orthogonal to the azimuthal direction. Positions to which the ultrasonic detecting pulses DP are transmitted with respect to the positions of the push pulses PP1 -- PP13 lie in the azimuthal direction, although not particularly shown.

[0054] Moreover, in the embodiment described above, positions of acoustic lines along which the plurality of push pulses PP1 -- PP5 (or push pulses PP1 -- PP13) are to be transmitted for generating a plurality of shear waves to be combined lie at one position as viewed in a direction of the plane for which an ultrasonic image is to be produced, as shown in FIG. 6, etc.; however, the push pulses may be transmitted at a plurality of positions. In other words, push pulses, which are transmitted along a plurality of acoustic lines arranged side by side in a direction intersecting the direction of the plane for which an ultrasonic image is to be produced, may be transmitted at a plurality of positions in the direction of the plane for which an ultrasonic image is to be produced. In this case, shear waves generated by the plurality of push pulses transmitted at each of the plurality of positions in the direction of the plane for which an ultrasonic image is to be produced are combined together.

[0055] For example, the push pulses may be transmitted to a plurality of positions in the region of interest R in the direction of the plane for which an ultrasonic image is to be produced.

[0056] Moreover, the direction in which the plurality of acoustic lines sl1 -- sl5 (or push pulses PP1 -- PP13) are disposed may be any direction intersecting the direction of the plane for which an ultrasonic image is to be produced. However, the direction in which the plurality of acoustic lines sl1 -- sl5 (or acoustic lines sl1 -- sl13) are disposed may be desirably a direction generally orthogonal

to the direction of the plane for which an ultrasonic image is to be produced.

[0057] Furthermore, the push pulses PP1 -- PP5 (or push pulses PP1 -- PP13) may be simultaneously transmitted.

[Description of Reference Symbols]

1	Ultrasonic diagnostic apparatus
3	Transmission/reception (T/R) beamformer
8	Control section
6	Display section
42	Velocity-of-propagation calculating section
43	Elasticity-value calculating section
S11 -- S113	Acoustic line
PP1 -- PP13	Push pulse
DP	Ultrasonic detecting pulse

[Name of Document] SCOPE OF CLAIM FOR PATENT

[Claim 1]

An ultrasonic diagnostic apparatus, characterized in comprising:

an ultrasonic probe for performing transmission/reception of ultrasound; and

a transmission control section for transmitting an ultrasonic push pulse from said ultrasonic probe along each of a plurality of different acoustic lines arranged side by side in one direction, said transmission control section transmitting a plurality of said ultrasonic push pulses to biological tissue in time with when each of shear waves generated in said biological tissue by each respective one of said plurality of push pulses is combined together.

[Claim 2]

The ultrasonic diagnostic apparatus as recited in claim 1, characterized in that: said one direction is a direction intersecting a plane for which an ultrasonic image is to be produced.

[Claim 3]

The ultrasonic diagnostic apparatus as recited in claim 1 or 2, characterized in that: said transmission control section transmits from said ultrasonic probe ultrasonic detecting pulses for detecting said shear waves with respect to said push pulse at positions in a direction intersecting said one direction.

[Claim 4]

The ultrasonic diagnostic apparatus as recited in claim 3, comprising: a measurement-value calculating section for calculating a measurement value regarding elasticity of said biological tissue based on echo signals of said ultrasonic detecting pulses.

[Claim 5]

The ultrasonic diagnostic apparatus as recited in claim 4, comprising: a display section in which an elasticity image having a display mode corresponding to said measurement value calculated by said measurement-value calculating section is displayed in a two-dimensional region.

[Claim 6]

The ultrasonic diagnostic apparatus as recited in claim 4 or 5, wherein: said measurement value is a velocity of propagation of said shear waves.

[Claim 7]

The ultrasonic diagnostic apparatus as recited in claim 4 or 5, wherein: said measurement value is an elasticity value of biological tissue calculated based on the velocity of propagation of said shear waves.

[Claim 8]

The ultrasonic diagnostic apparatus as recited in any one of claims 1 -- 7, characterized in that: said transmission control section intermittently and consecutively transmits said push pulses.

[Claim 9]

An ultrasonic diagnostic apparatus, characterized in comprising:

an ultrasonic probe for performing transmission/reception of ultrasound; and

a processor for executing, by a program, a transmission control function of transmitting an ultrasonic push pulse from said ultrasonic probe along each of a plurality of different acoustic lines arranged side by side in one direction, said transmission control function transmitting a plurality of said ultrasonic push pulses to biological tissue in time with when each of shear waves generated in said biological tissue by each respective one of said plurality of push pulses is combined together.

[Claim 10]

A program characterized in causing a processor in an ultrasonic diagnostic apparatus to execute: a transmission control function of transmitting an ultrasonic push pulse from an ultrasonic probe along each of a plurality of different acoustic lines arranged side by side in one direction, said transmission control function transmitting a plurality of said ultrasonic push pulses to biological tissue in time with when each of shear waves generated in said biological tissue by each respective one of said plurality of push pulses is combined together.

FIG.1

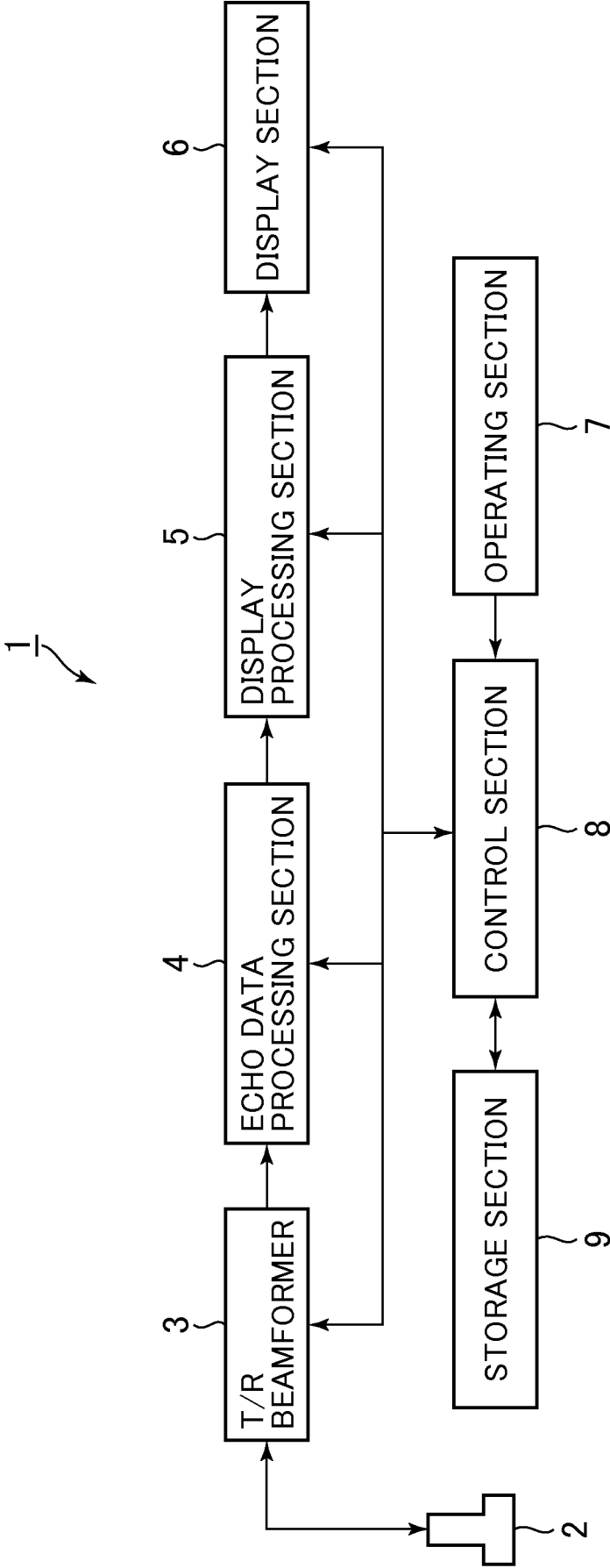


FIG.2

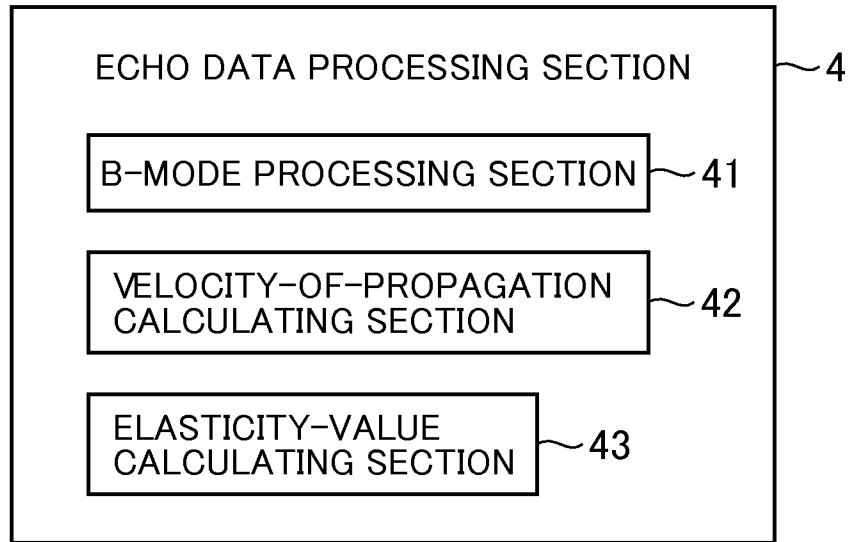


FIG.3

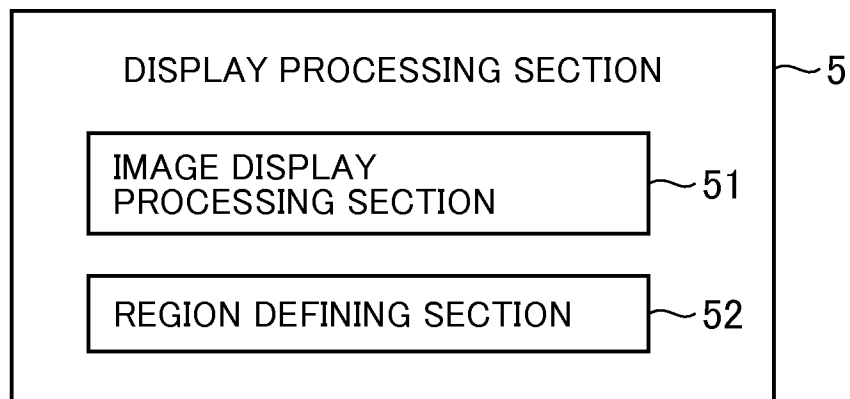


FIG.4

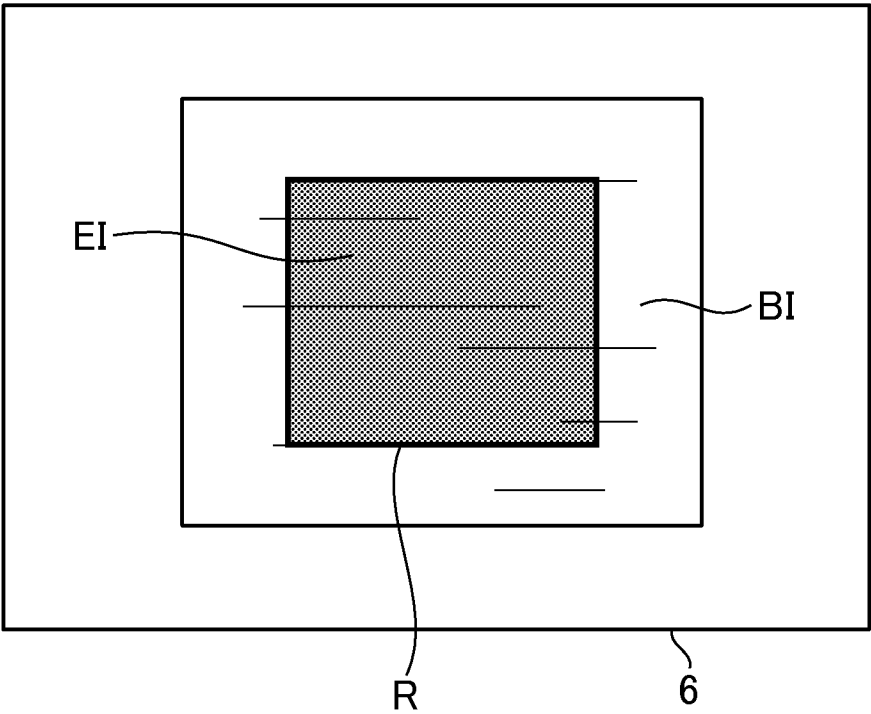


FIG.5

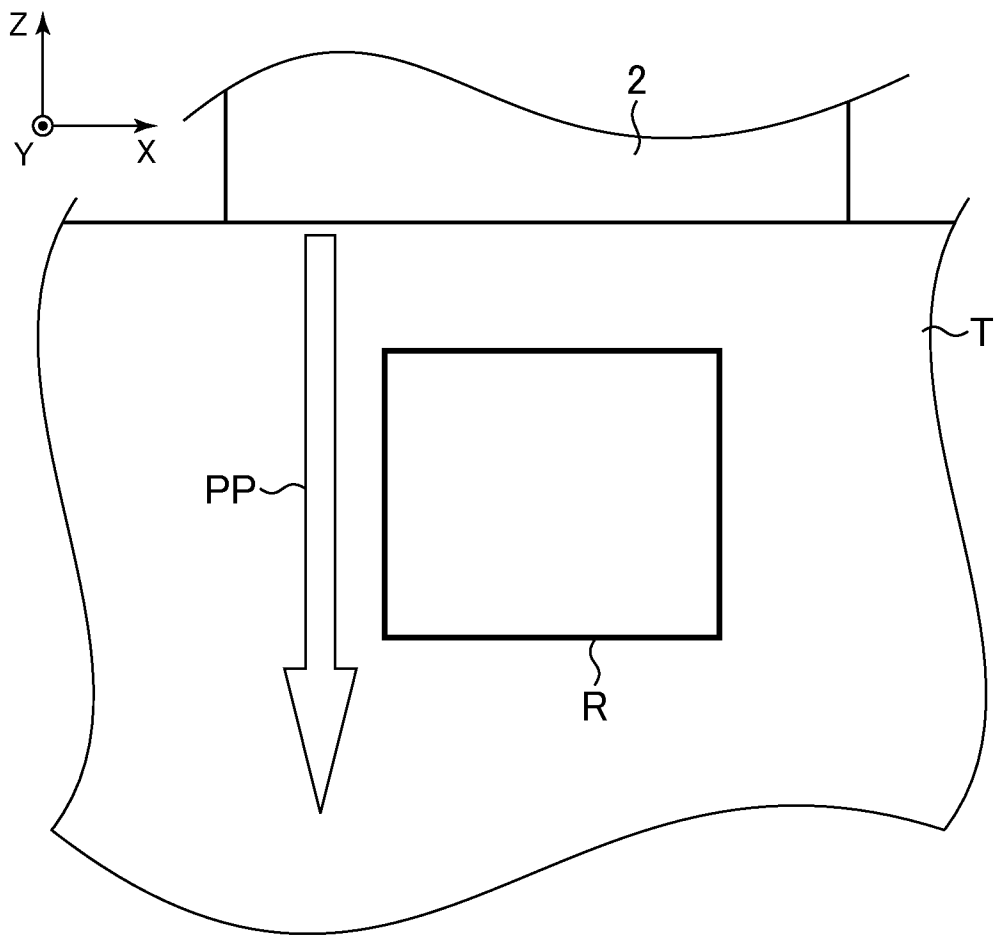


FIG.6

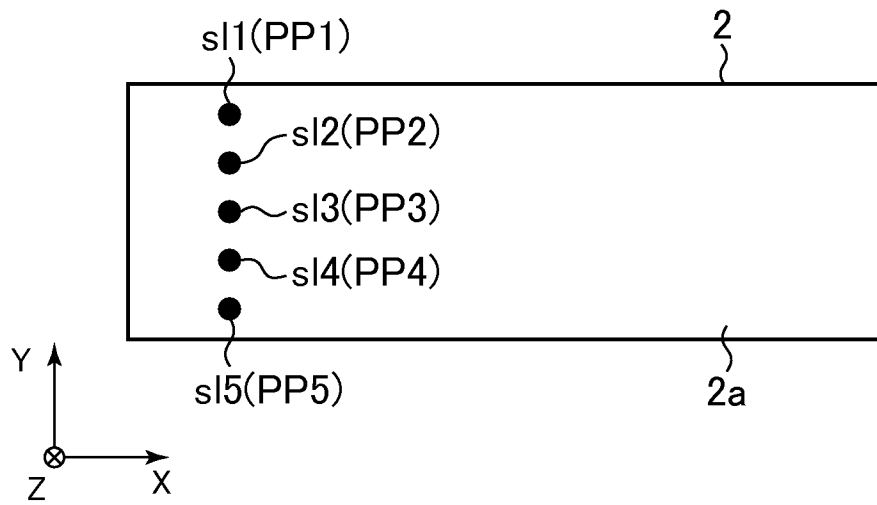


FIG.7

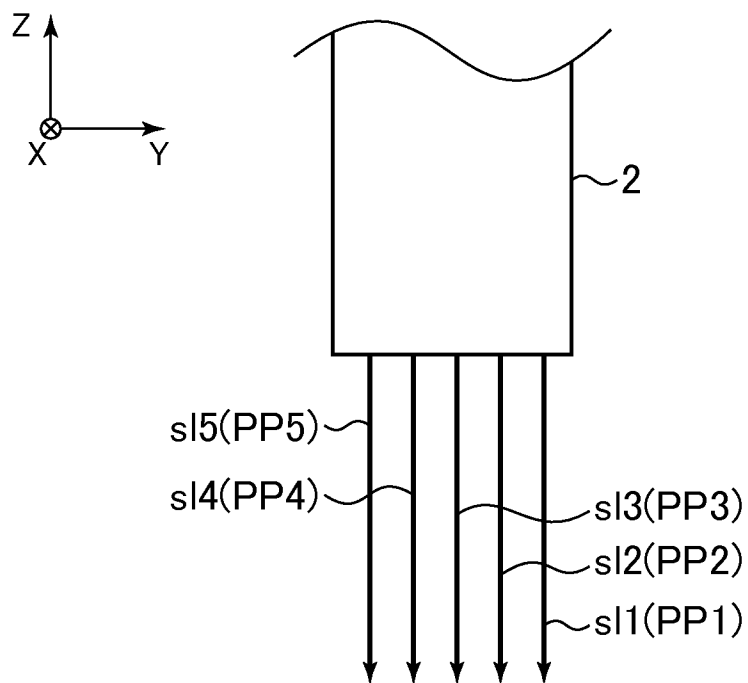


FIG.8

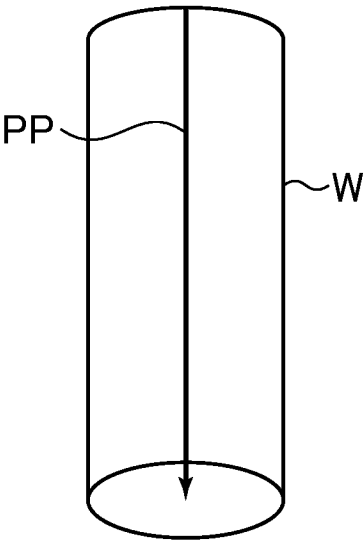


FIG.9

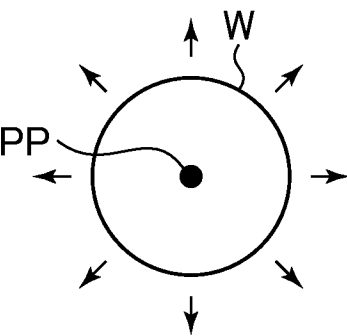


FIG.10

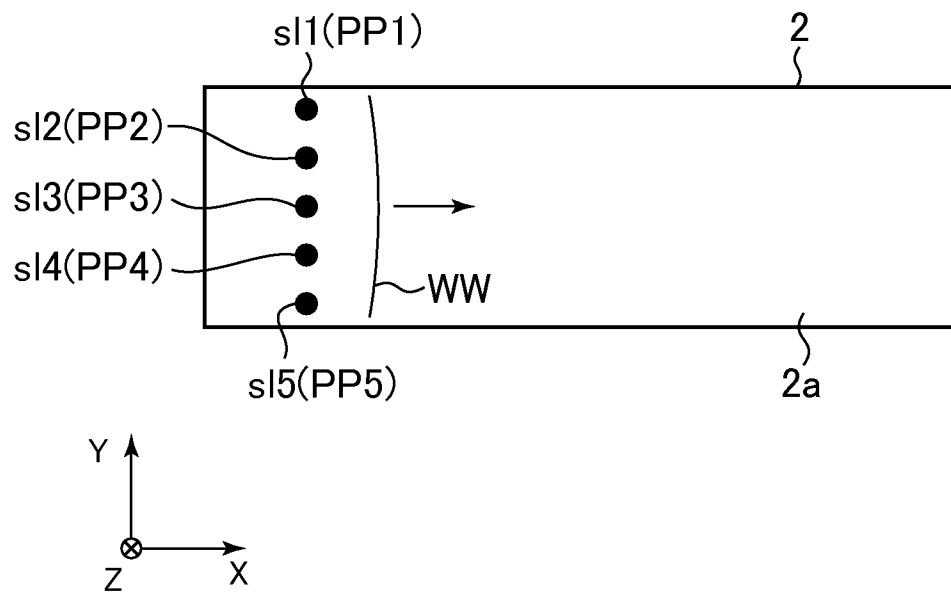


FIG.11

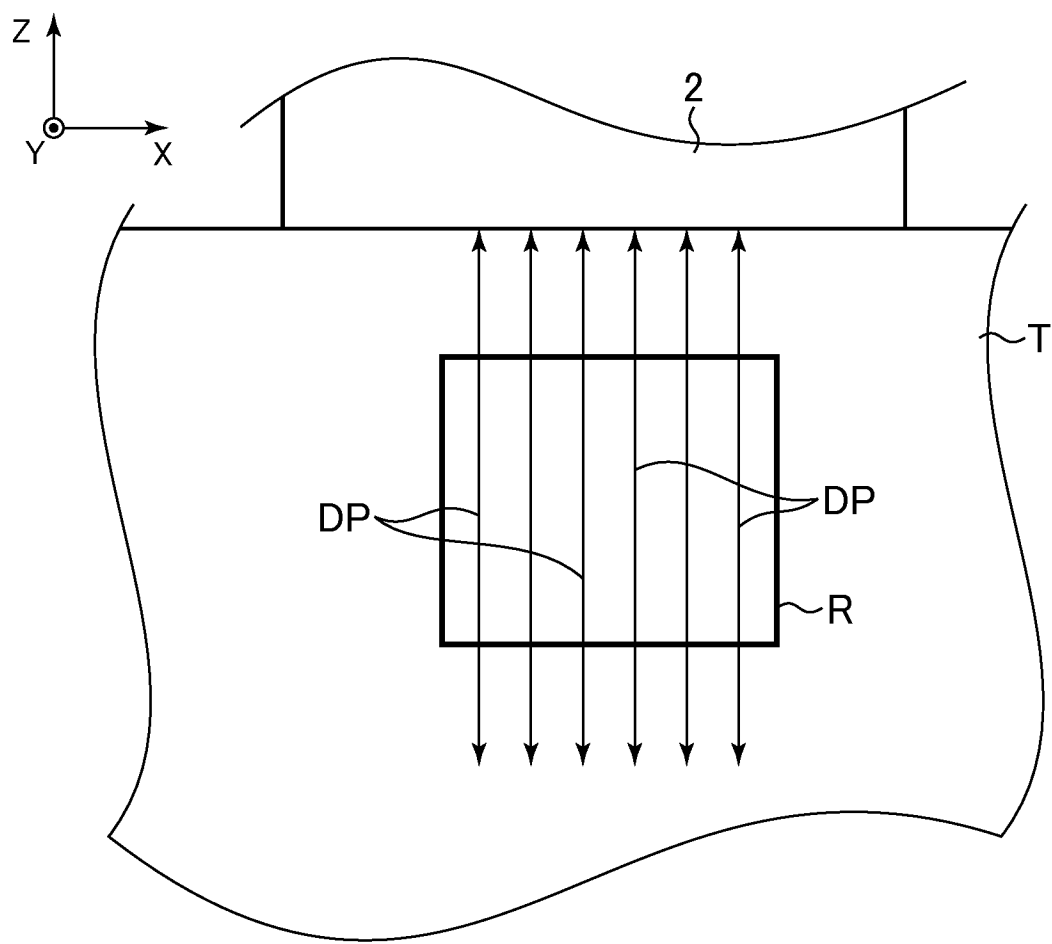
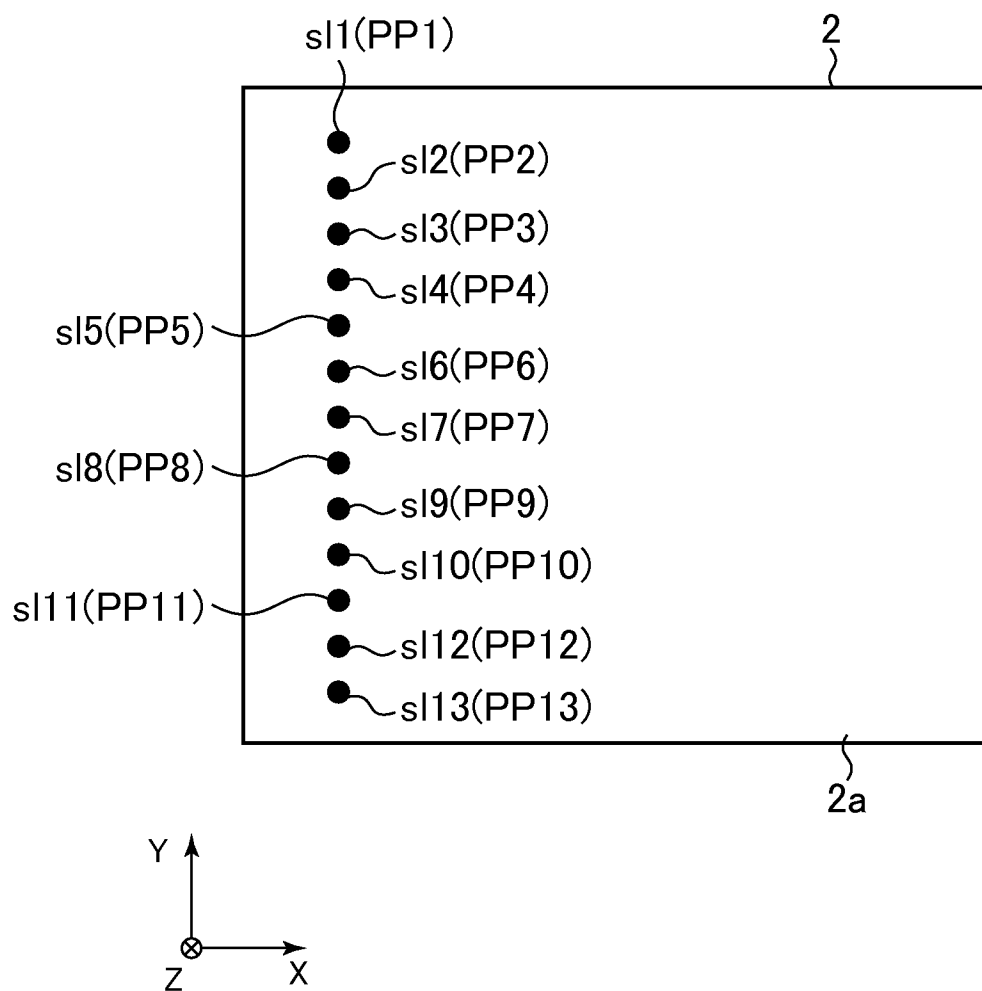


FIG.12



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/037555

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B8/08 A61B8/00 G01S7/52
ADD.

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)
A61B 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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/046173 A1 (GREENLEAF JAMES F [US] ET AL) 13 February 2014 (2014-02-13) paragraphs [0041], [4573]; figure 2c -----	1-10
X	HENG ZHAO ET AL: "Shear Wave Speed Measurement Using an Unfocused Ultrasound Beam", ULTRASOUND IN MEDICINE & BIOLOGY, vol. 38, no. 9, 1 September 2012 (2012-09-01), pages 1646-1655, XP055208999, ISSN: 0301-5629, DOI: 10.1016/j.ultrasmedbio.2012.05.015 page 1647, left-hand column -----	1,9,10
A	US 2011/066030 A1 (YAO LINXIN [US]) 17 March 2011 (2011-03-17) figure 7 ----- -/-	1-10



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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