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(54) **ULTRASONIC TREATMENT APPARATUS**

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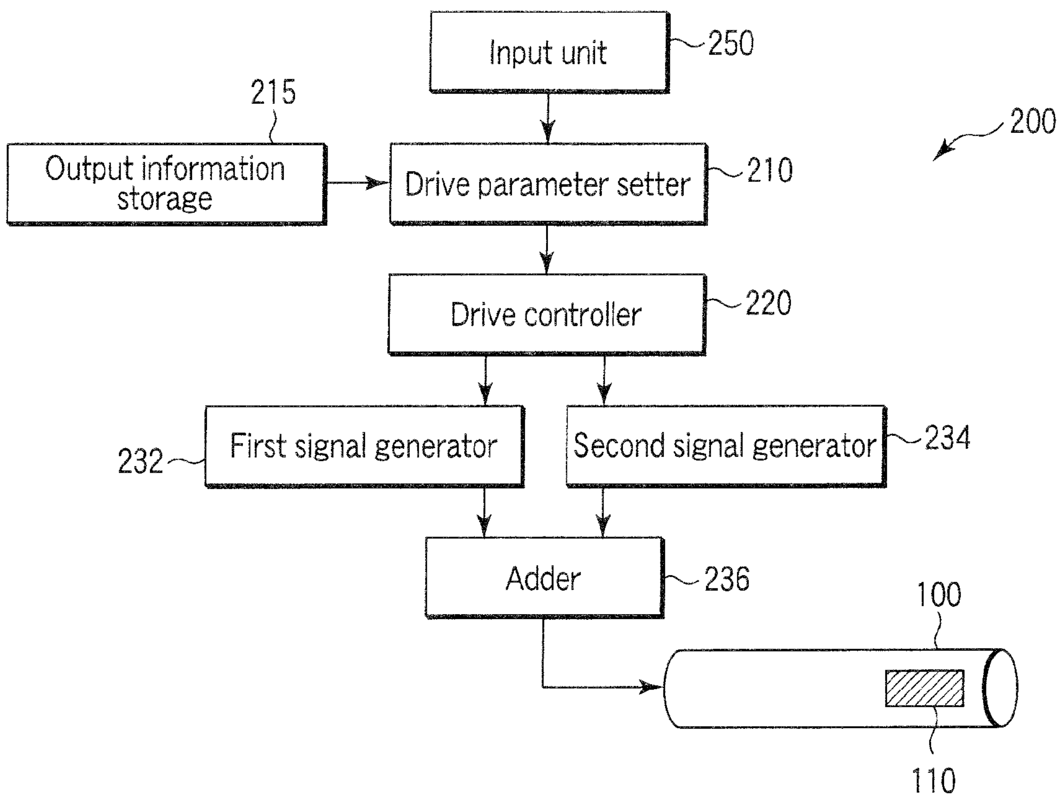
(57) **ABSTRACT**

An ultrasonic treatment apparatus includes a sound source, a frequency setter and a drive signal generator. The sound source emits ultrasonic waves. The ultrasonic waves are finite amplitude acoustic waves including a first signal frequency and a second signal frequency. The frequency setter sets the first signal frequency and the second signal frequency in accordance with a target position of a treatment object with respect to the sound source. The drive signal generator is configured to generate a drive signal and to drive the sound source. The drive signal is a signal which causes the sound source to emit the ultrasonic waves.



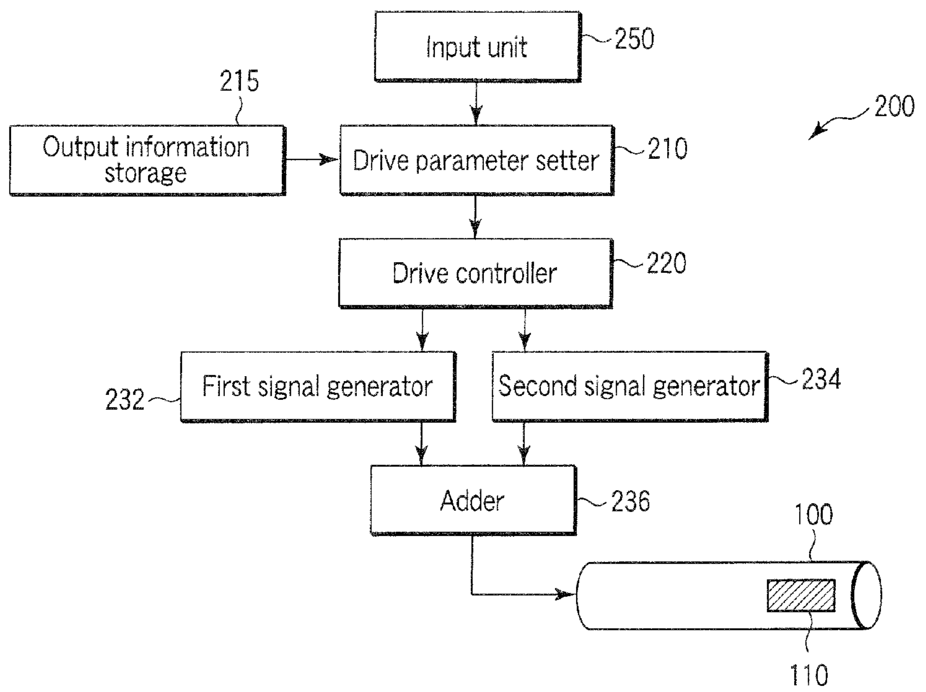

Input unit
250
215
Output information storage
Drive parameter setter
210
200
Drive controller
220
232
First signal generator
Second signal generator
234
Adder
236
100
110

FIG. 1

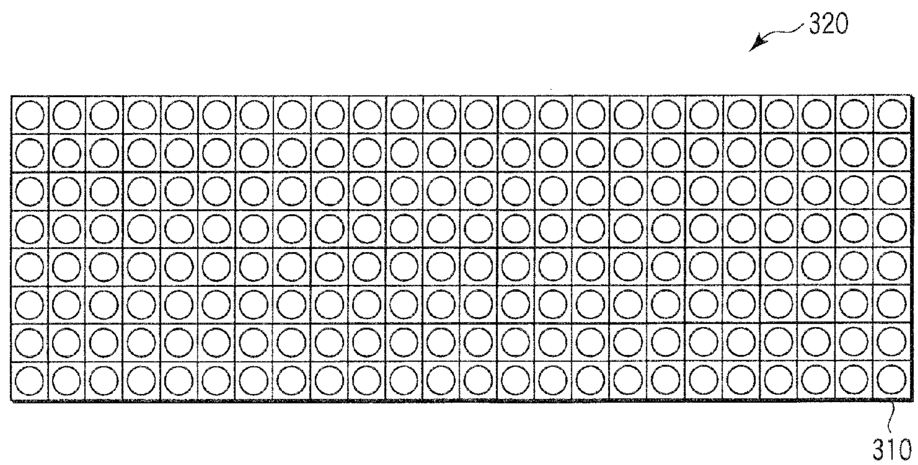
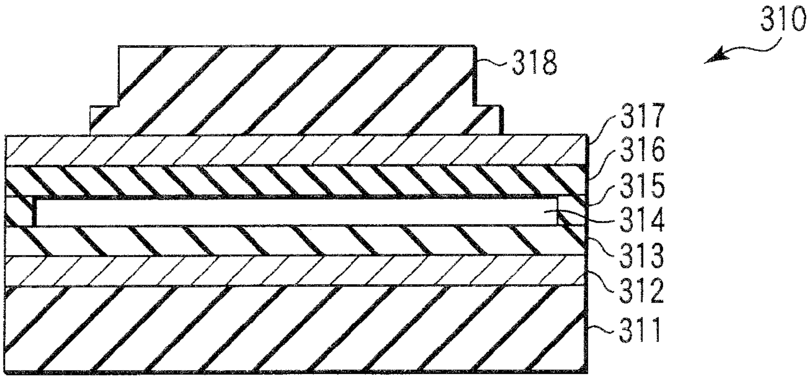
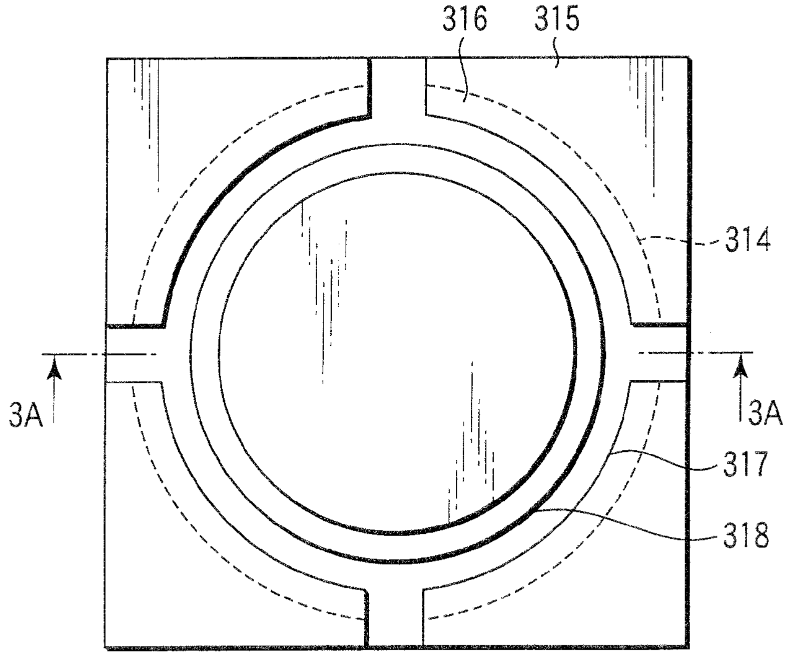

320
310

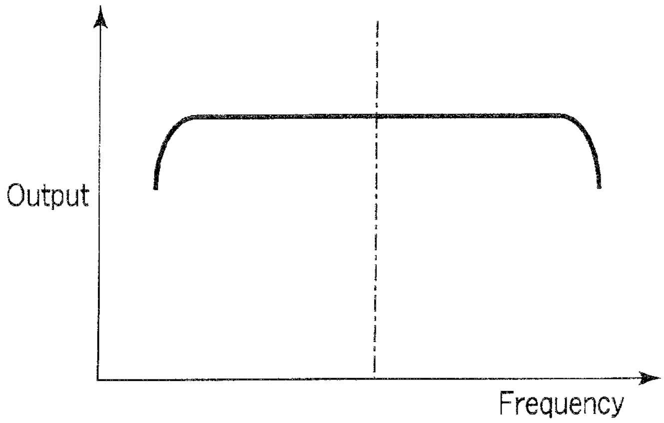
FIG. 2



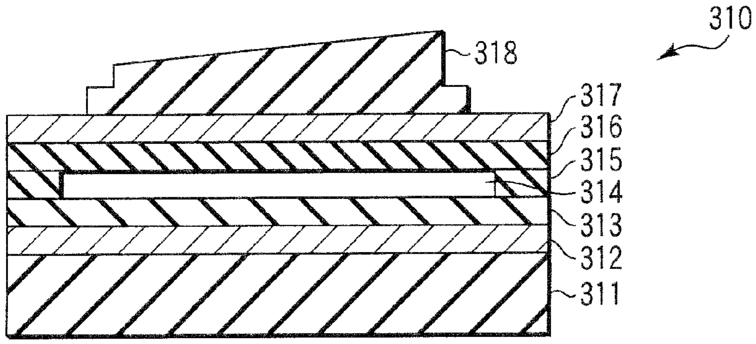
F I G. 3A



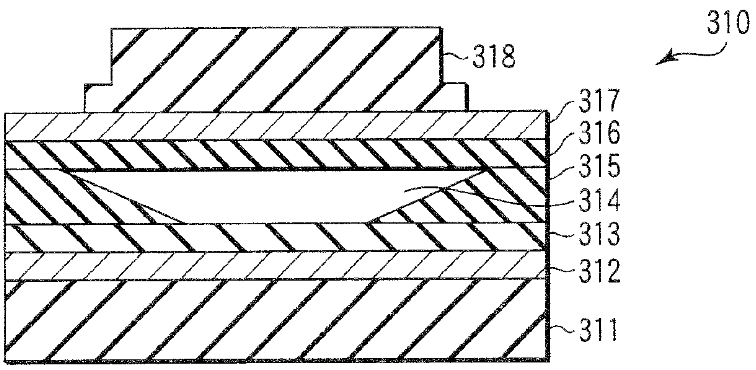
F I G. 3B



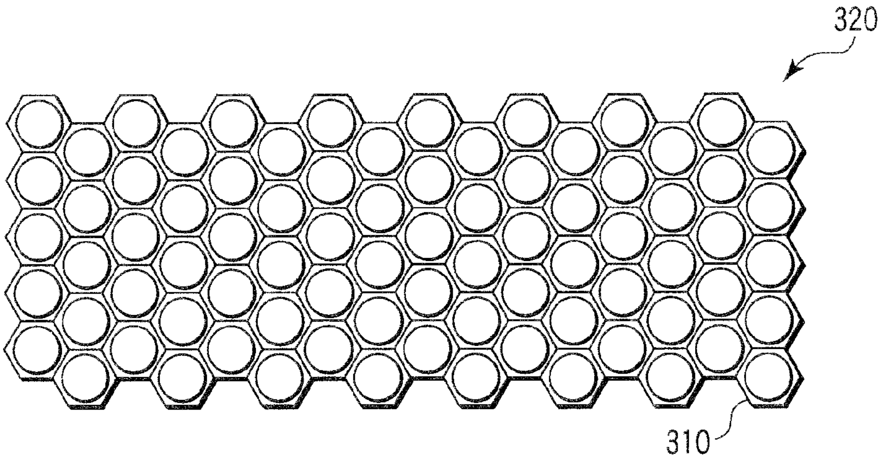
F I G. 4



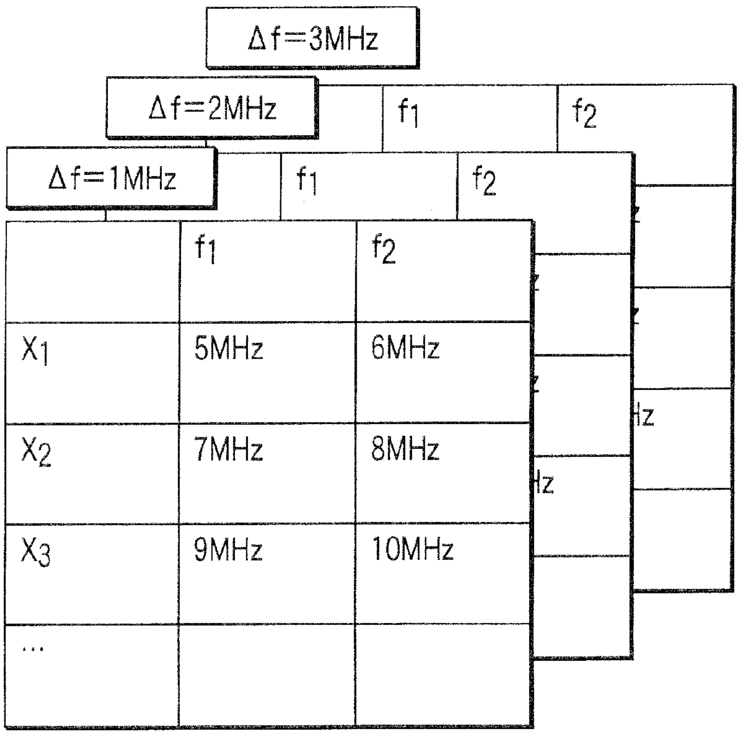
F I G. 5



F I G. 6


320
310

F I G. 7


Δf=3MHz
Δf=2MHz
Δf=1MHz
f1
f2
X1
5MHz
6MHz
X2
7MHz
8MHz
X3
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10MHz
...

F I G. 8

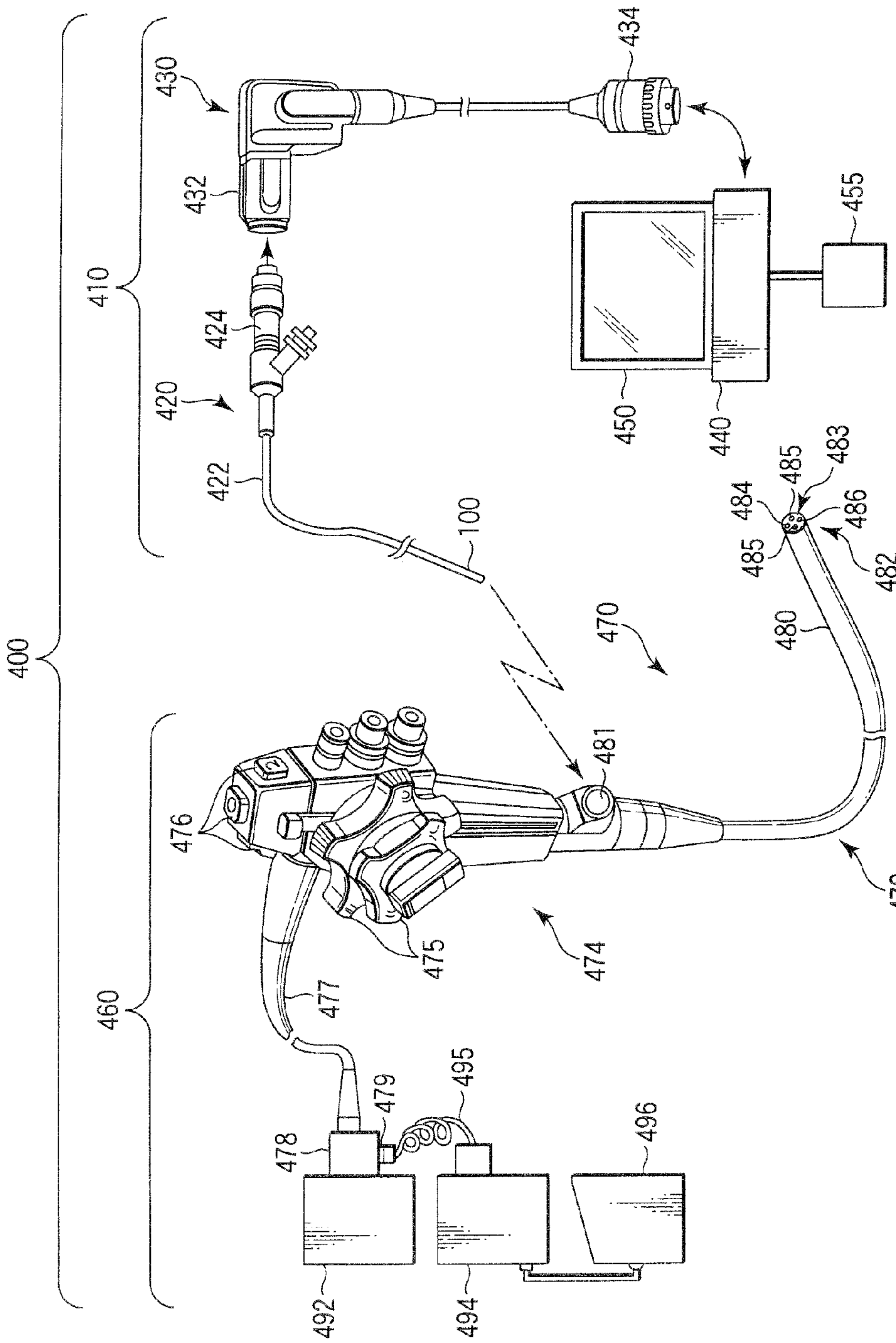
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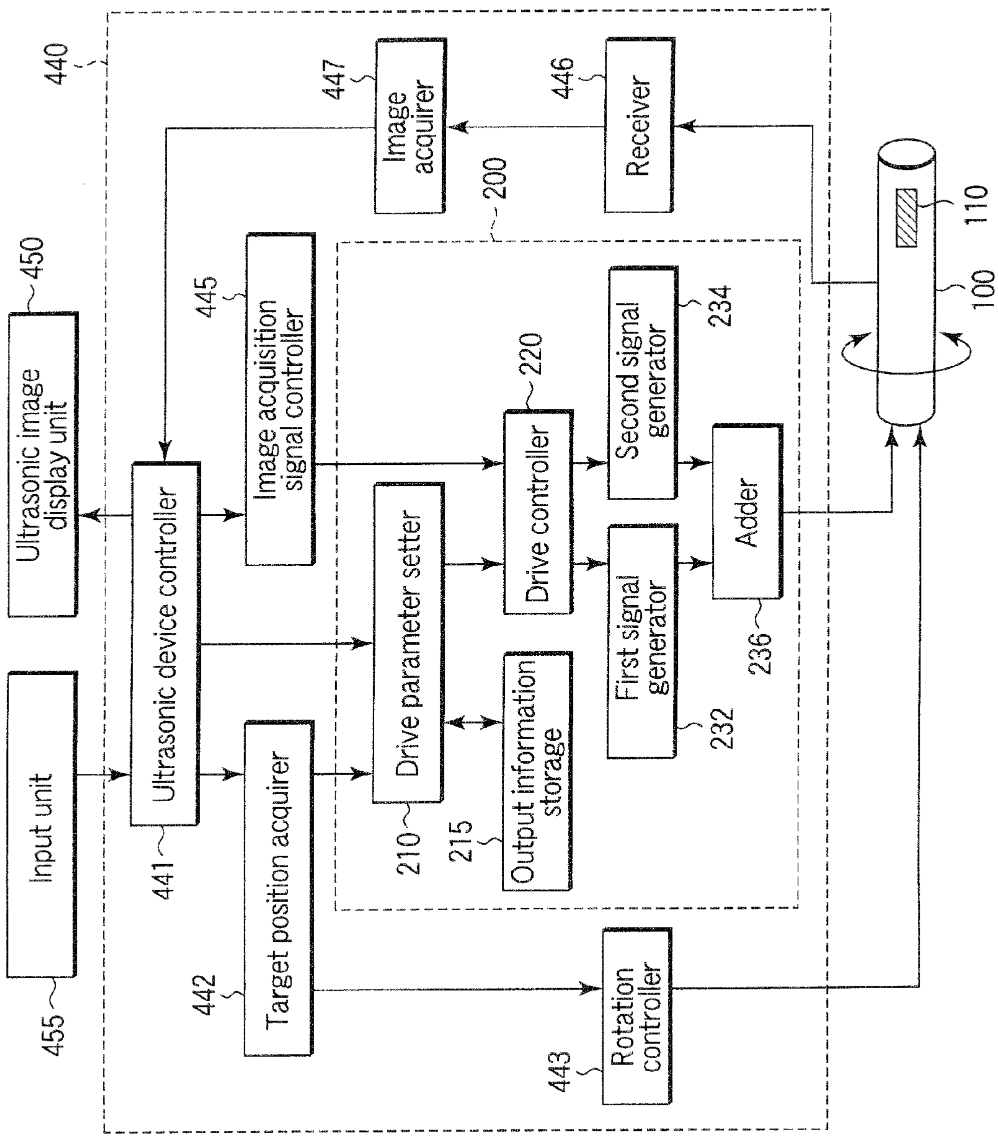
FIG. 9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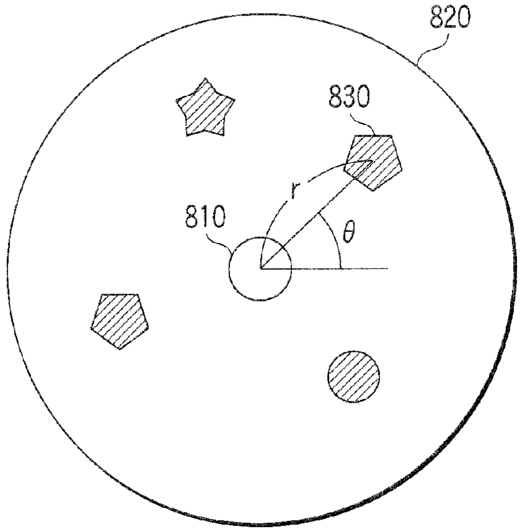
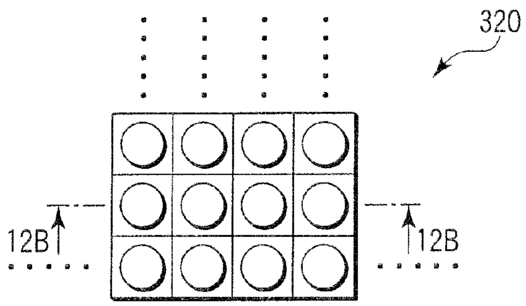
447
Image acquirer
446
Receiver
200
110
100
450
Ultrasonic image display unit
445
Image acquisition signal controller
220
Drive controller
234
Second signal generator
Adder
236
Drive parameter setter
First signal generator
232
Output information storage
215
210
Input unit
Ultrasonic device controller
441
Target position acquirer
442
455
Rotation controller
443

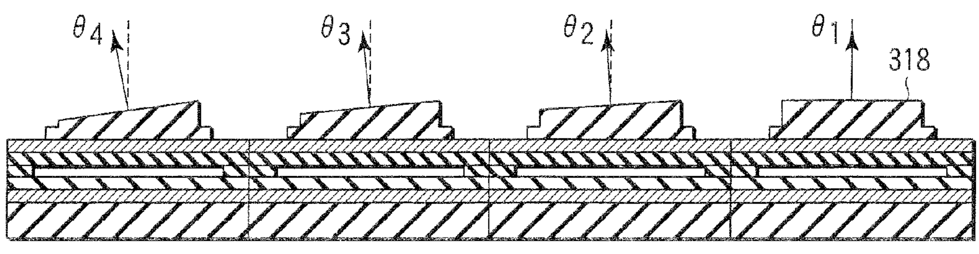
F I G. 10



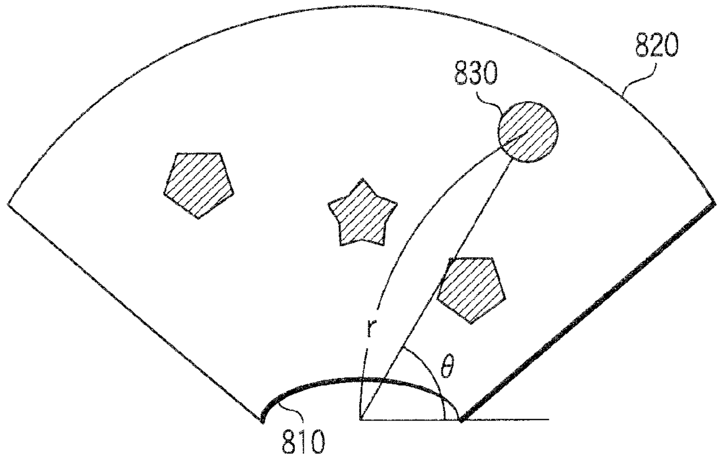
F I G. 11



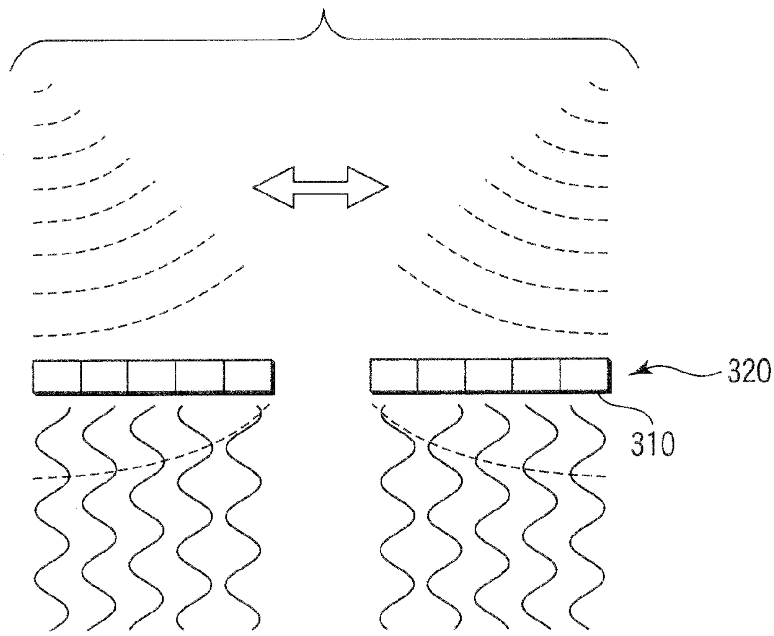
F I G. 12A



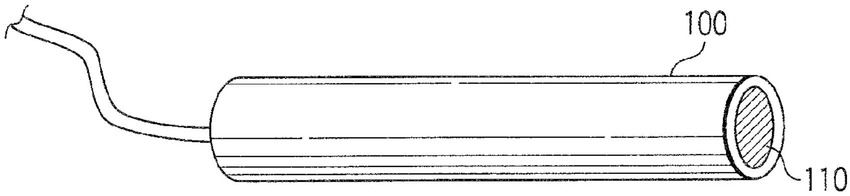
F I G. 12B



F I G. 13



F I G. 14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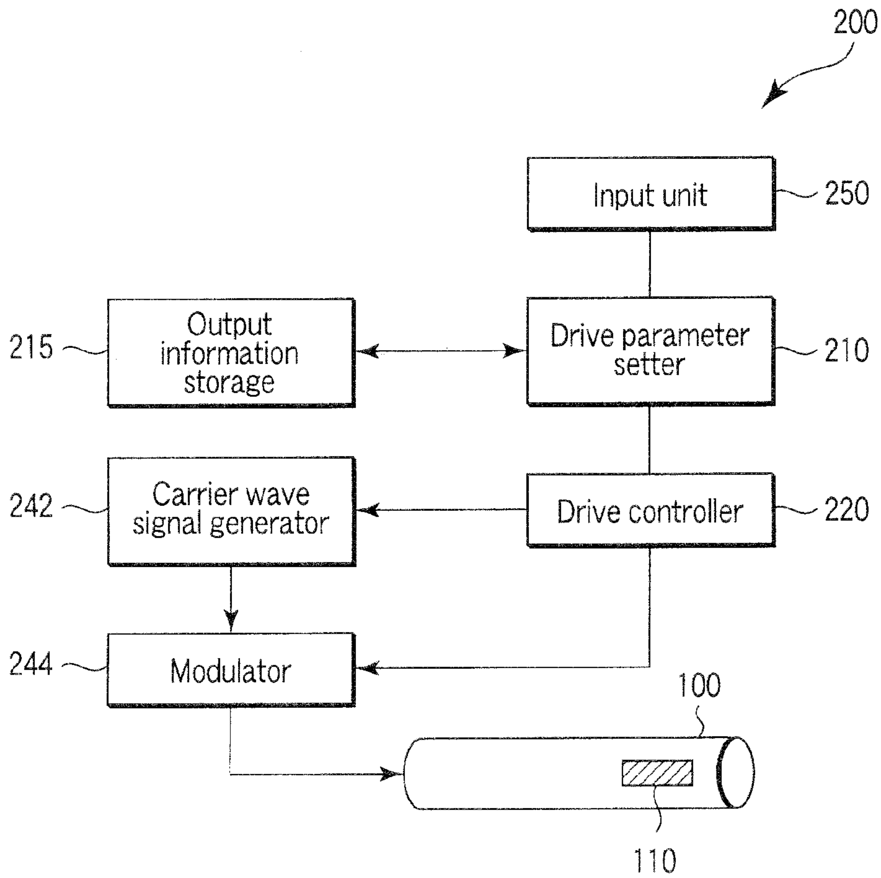
F I G. 15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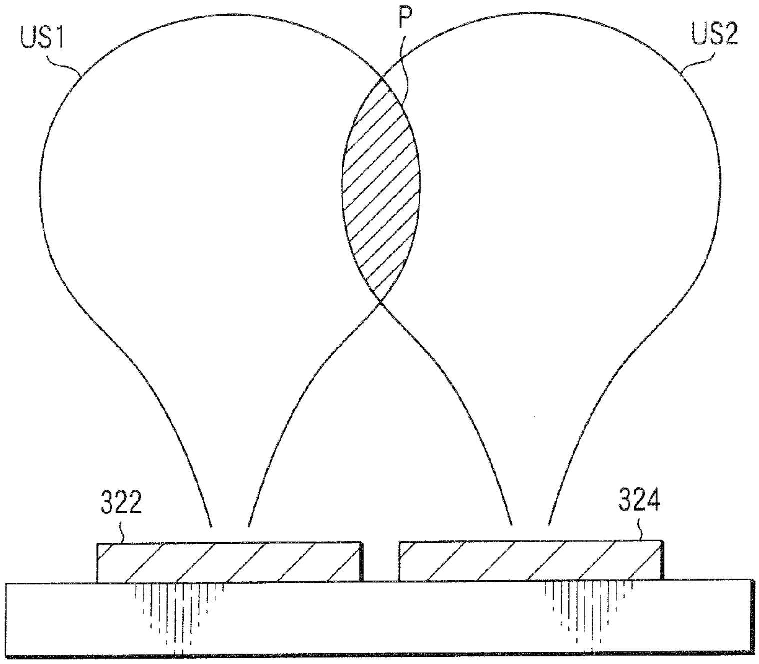
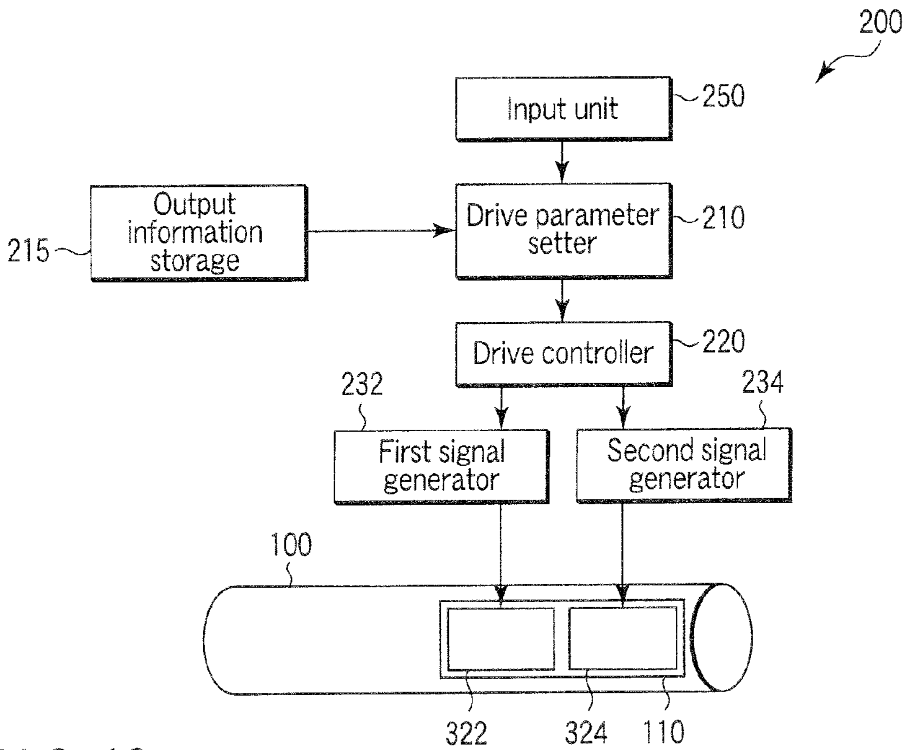
250
Output information storage
215
Drive parameter setter
210
Carrier wave signal generator
242
Drive controller
220
Modulator
244
100
110

F I G. 16


US1
P
US2
322
324

F I G. 17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Input unit
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Output information storage
215
Drive parameter setter
210
Drive controller
220
232
234
First signal generator
Second signal generator
100
322
324
110

F I G. 18

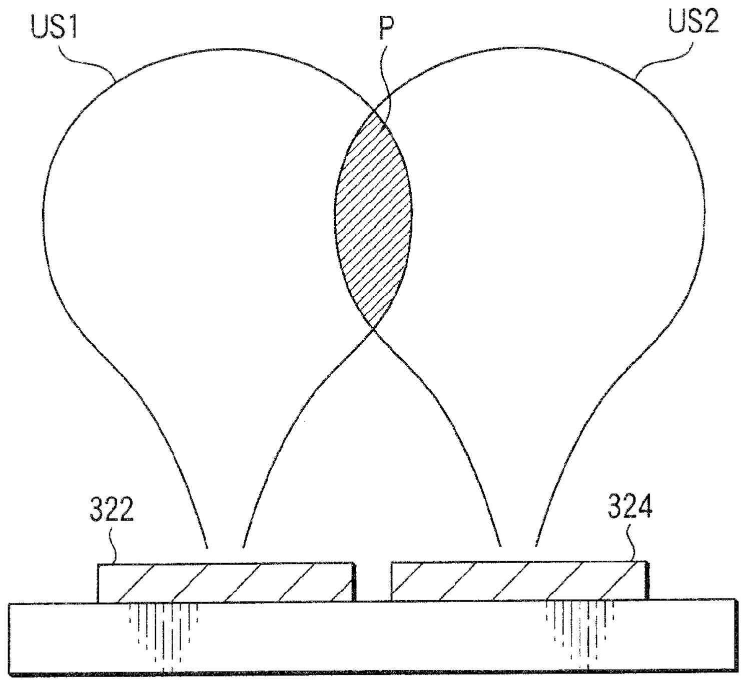


FIG. 19A

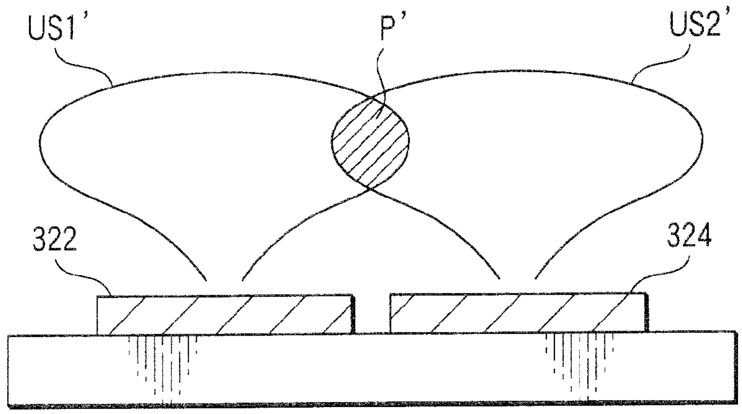
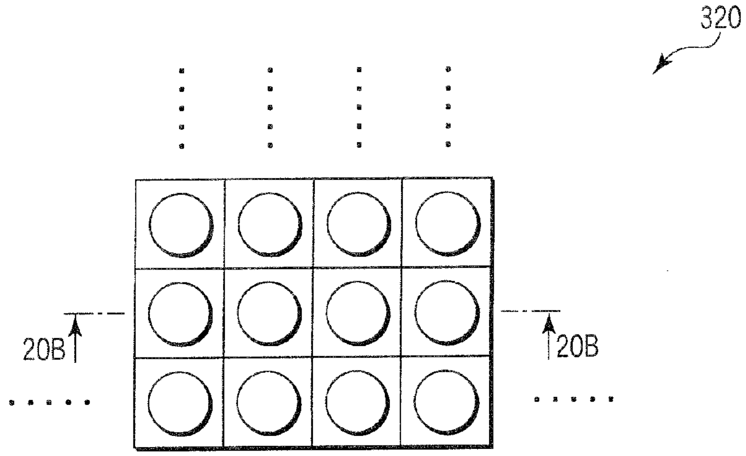
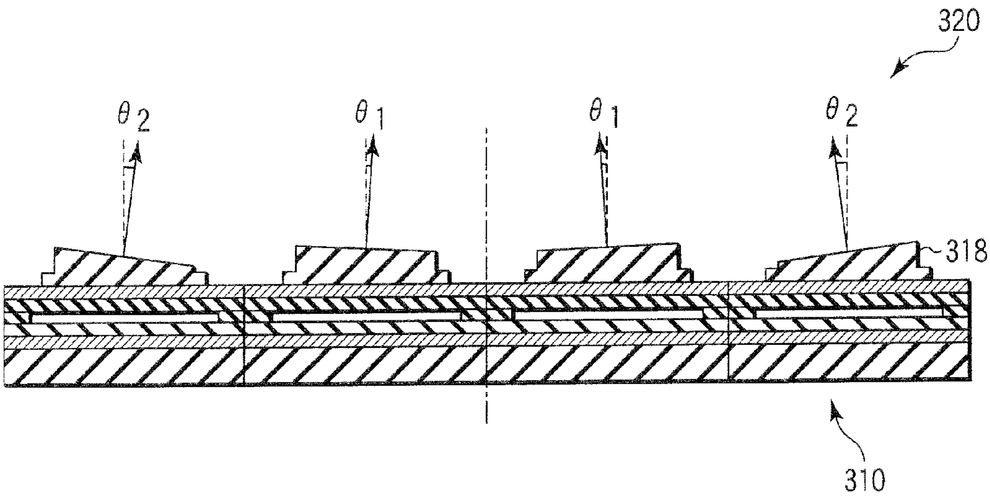


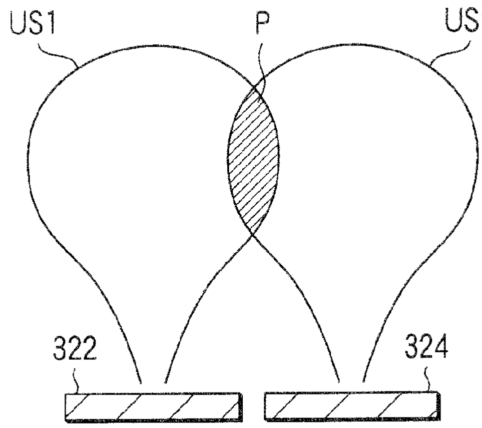
FIG. 19B



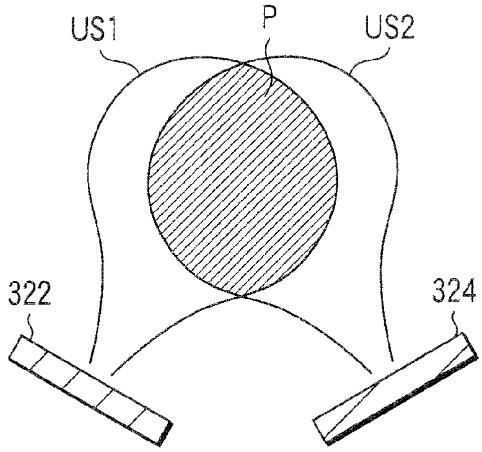
F I G. 20A



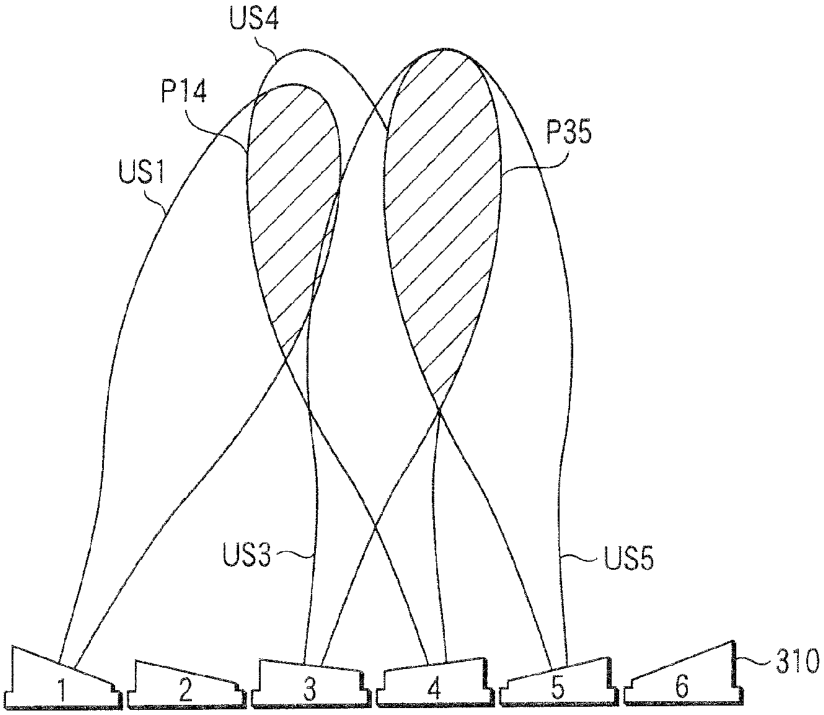
F I G. 20B



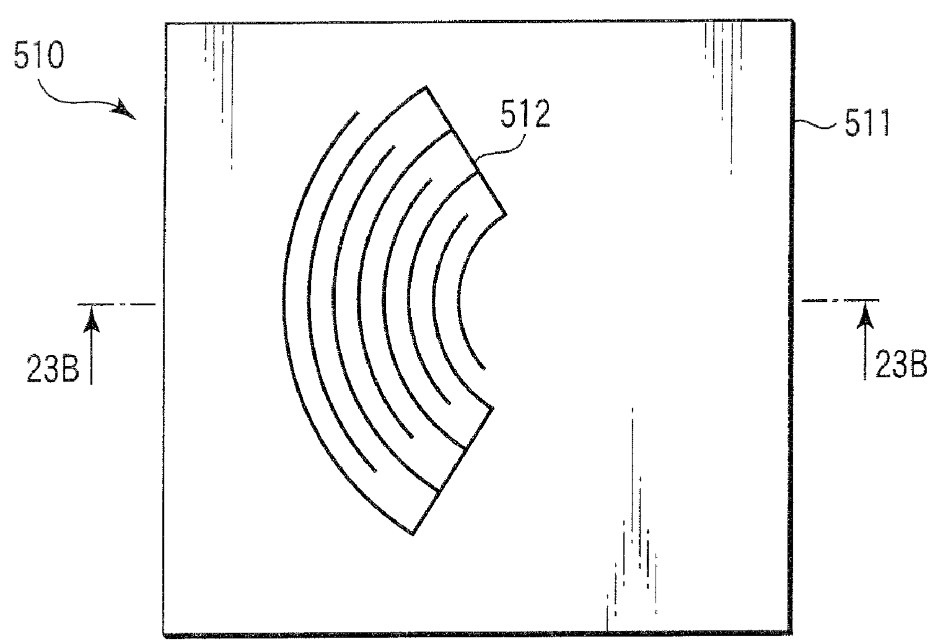
F I G. 21A



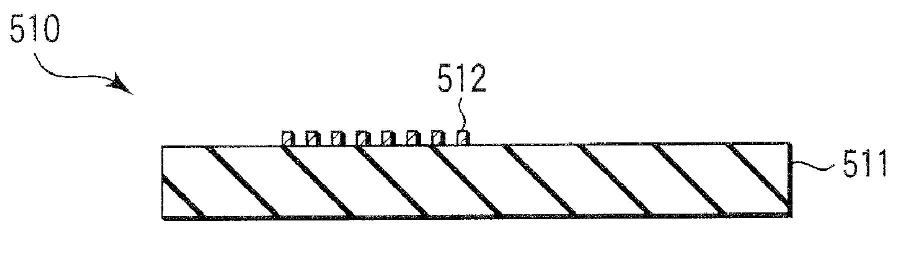
F I G. 21B



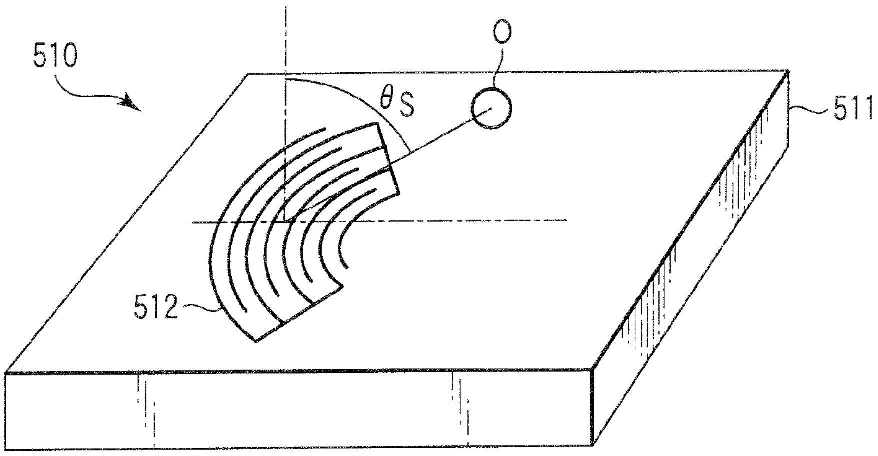
F I G. 22



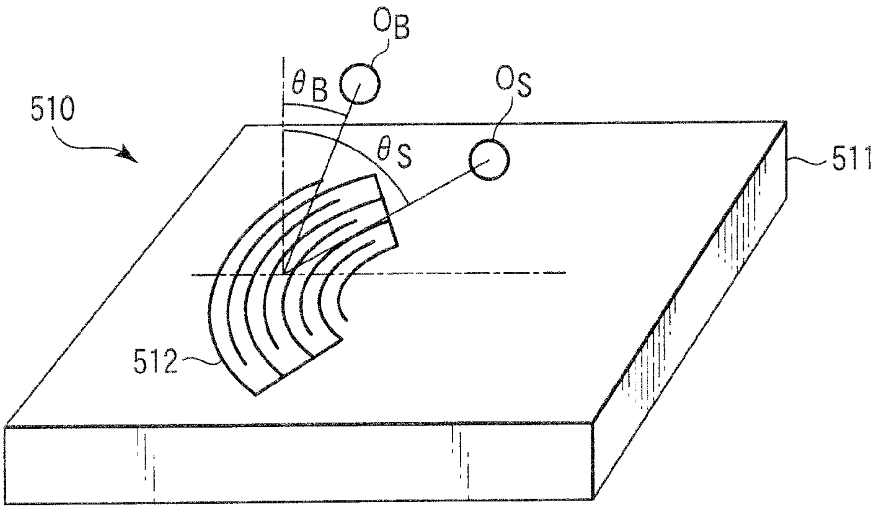
F I G. 23A



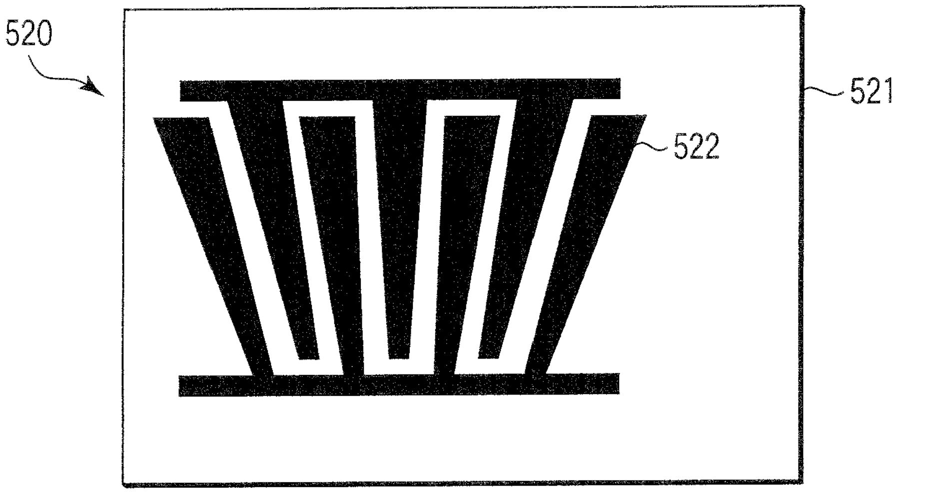
F I G. 23B



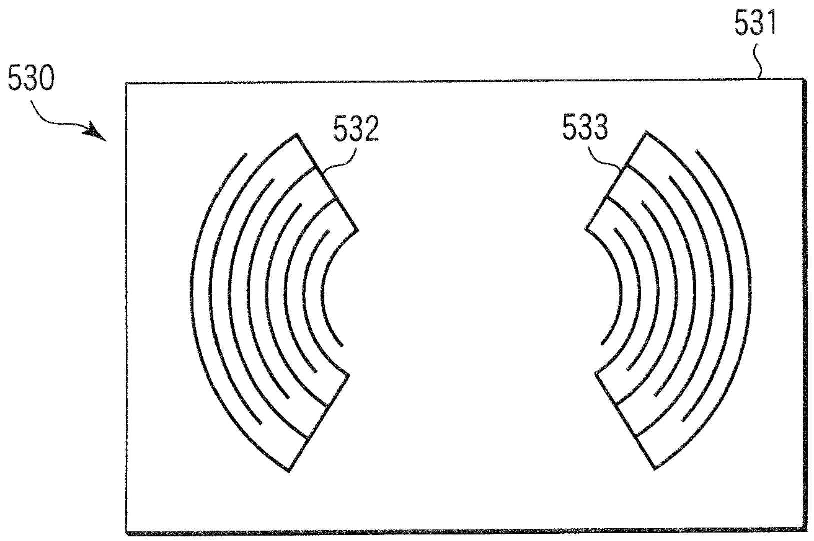
F I G. 24



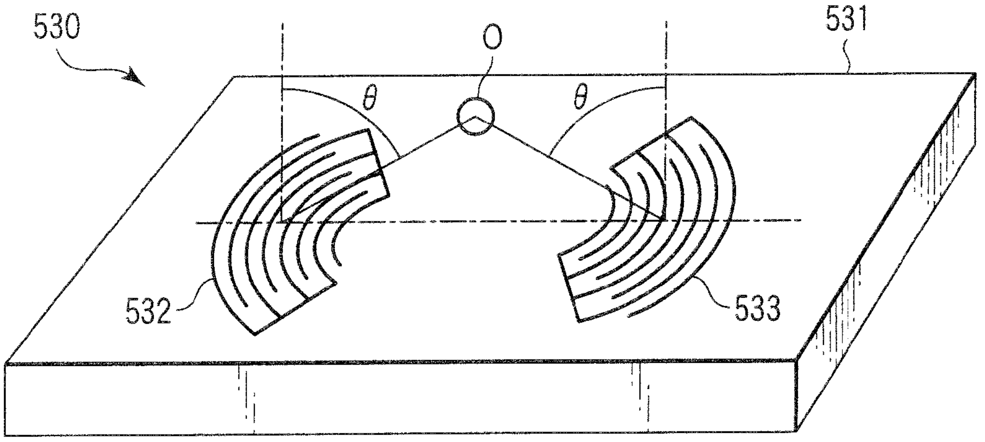
F I G. 25



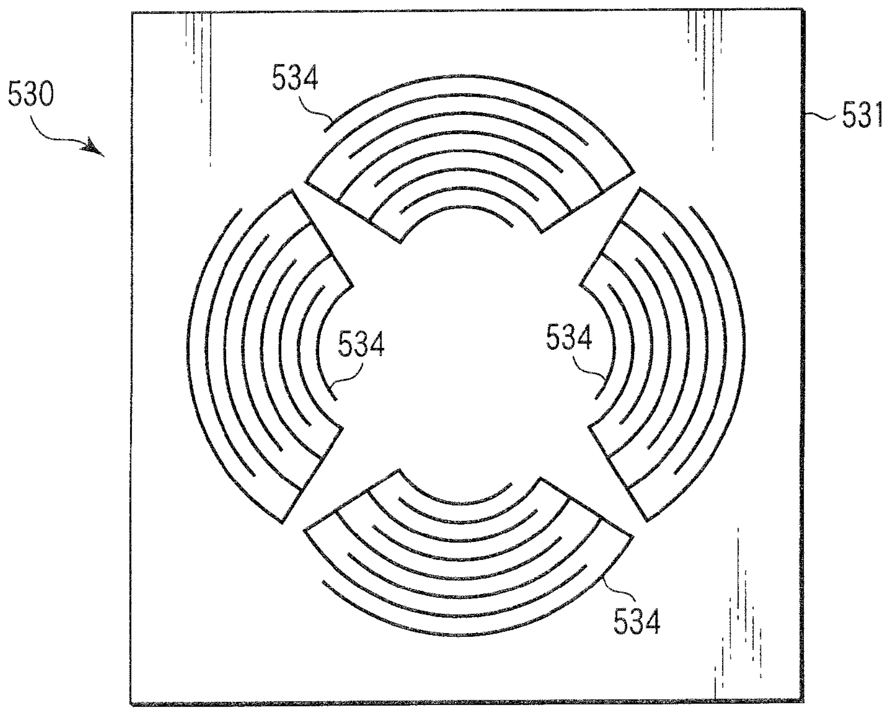
F I G. 26



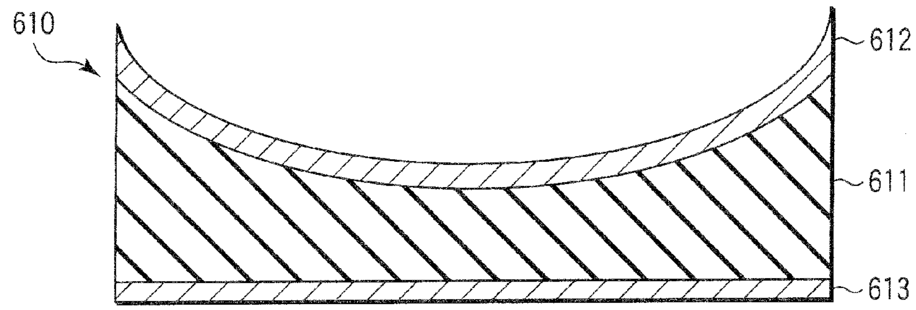
F I G. 27



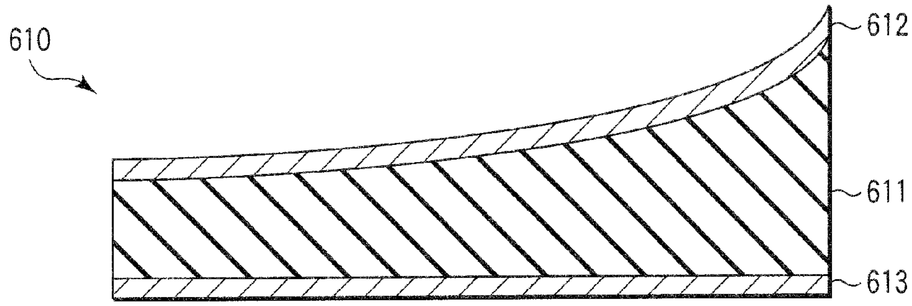
F I G. 28



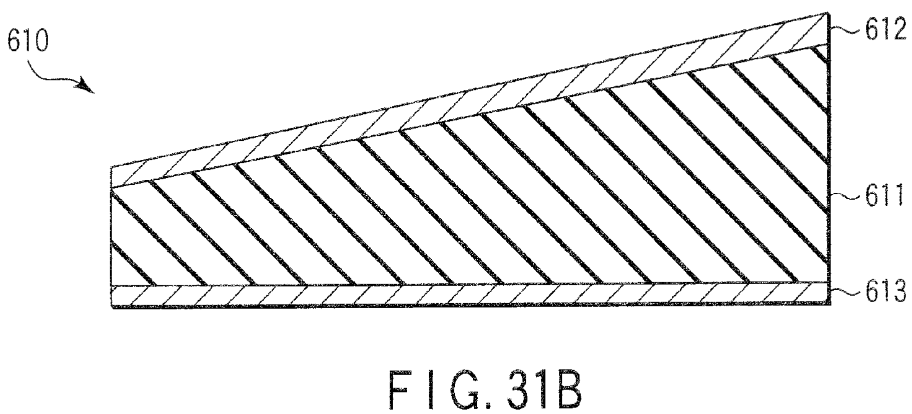
F I G. 29



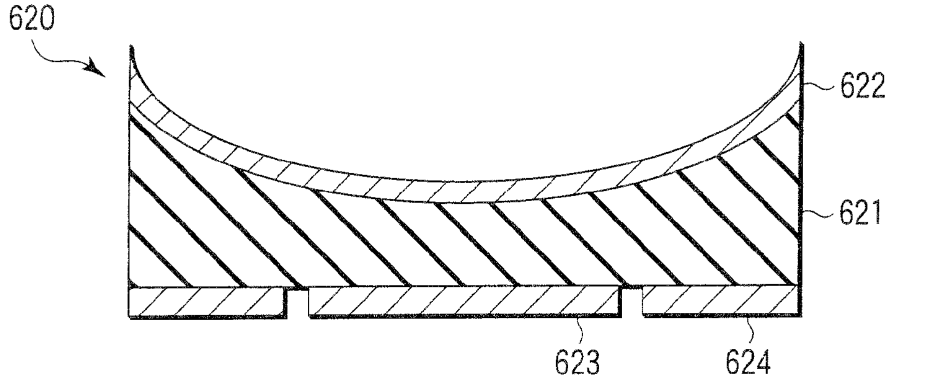
F I G. 30



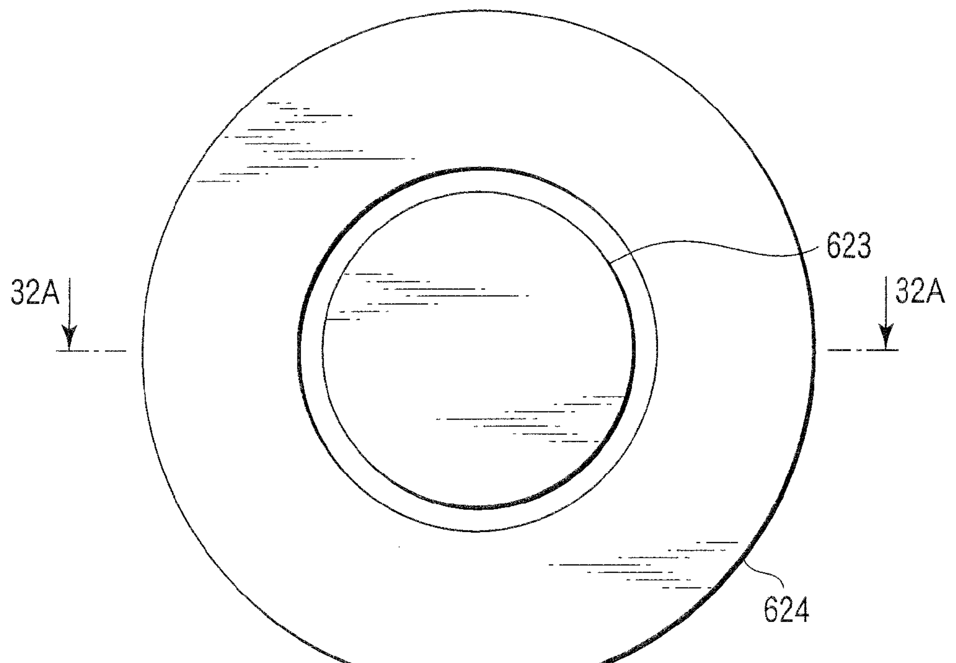
F I G. 31A



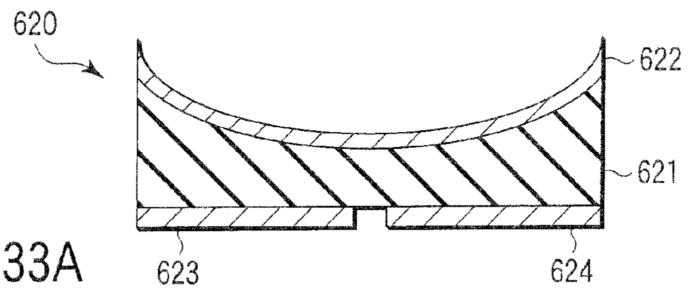
F I G. 31B



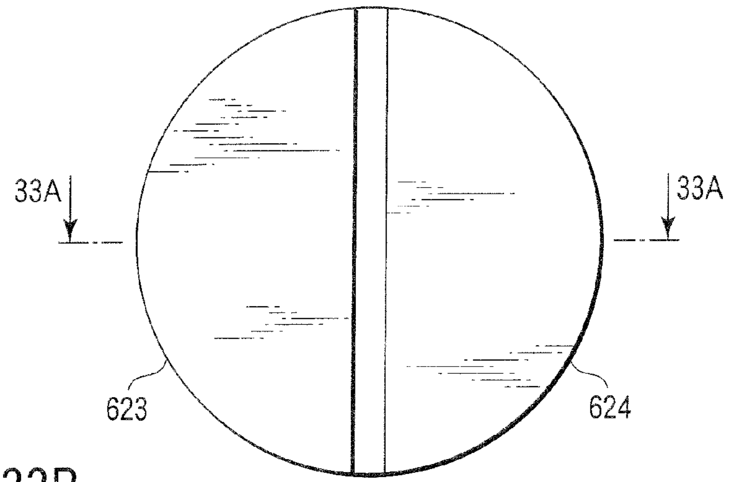
F I G. 32A



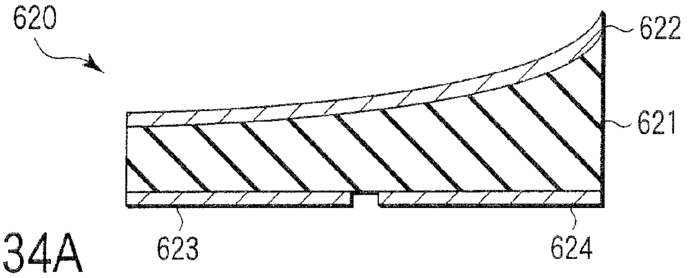
F I G. 32B



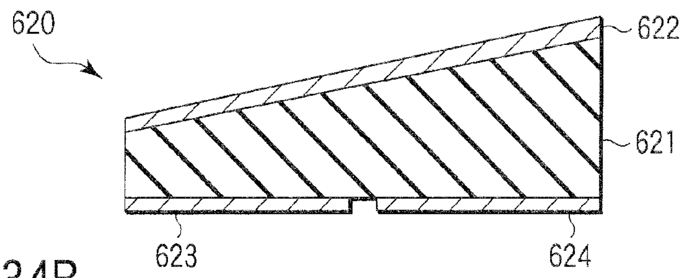
F I G. 33A



F I G. 33B



F I G. 34A



F I G. 34B

ULTRASONIC TREATMENT APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from prior Japanese Patent Application No, 2010-042570, filed Feb. 26, 2010, the entire contents 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 treatment apparatus.

[0004] 2. Description of the Related Art

[0005] According to one general treatment technique, ultrasonic waves are applied to a target tissue by an ultrasonic radiation device to destroy cells constituting the tissue or to heat and coagulate the tissue. An ultrasonic treatment apparatus for use in such a treatment is disclosed in, for example, Jpn. Pat. Appln. KOKAI Publication No. 2004-113254. It is known that the propagation distance of ultrasonic waves varies depending on the frequency of the ultrasonic waves. For example, the above-mentioned publication also discloses that ultrasonic wave generating elements are exchanged to change the frequency of ultrasonic waves to be radiated depending on a position to be irradiated with ultrasonic waves.

[0006] It is known that in the above-mentioned ultrasonic irradiation treatment, if microbubbles used as an ultrasonic contrast agent are provided to the target tissue and the microbubbles are vibrated or burst by ultrasonic irradiation, the efficiency of this treatment increases as a result of a cavitation effect.

BRIEF SUMMARY OF THE INVENTION

[0007] According to an aspect of the invention, an ultrasonic treatment apparatus includes a sound source which emits ultrasonic waves, the ultrasonic waves being finite amplitude acoustic waves including a first signal frequency and a second signal frequency; a frequency setter which sets the first signal frequency and the second signal frequency in accordance with a target position of a treatment object with respect to the sound source; and a drive signal generator configured to generate a drive signal and to drive the sound source, the drive signal being a signal which causes the sound source to emit the ultrasonic waves.

[0008] Advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. Advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0009] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

[0010] FIG. **1** is a block diagram showing a configuration example of an ultrasonic treatment apparatus according to a first embodiment of the present invention;

[0011] FIG. **2** is a plane view showing an example of a cMUT array constituting an ultrasonic emitter according to the first embodiment of the present invention;

[0012] FIG. **3**A is a sectional view showing an example of a cMUT constituting the ultrasonic emitter according to the first embodiment of the present invention;

[0013] FIG. **3**B is a plane view showing an example of a cMUT constituting the ultrasonic emitter according to the first embodiment of the present invention;

[0014] FIG. **4** is a schematic graph illustrating the frequency characteristics of an output of the ultrasonic treatment apparatus according to the first embodiment of the present invention;

[0015] FIGS. **5** and **6** are sectional views showing other examples of the cMUT constituting the ultrasonic emitter according to the first embodiment of the present invention;

[0016] FIG. **7** is a sectional view showing another example of the cMUT constituting the ultrasonic emitter according to the first embodiment of the present invention;

[0017] FIG. **8** is a diagram showing an example of tables which are stored in an output information storage according to the first embodiment of the present invention and which represent the relation between the depths of target positions and output frequencies;

[0018] FIG. **9** is a diagram showing a configuration example of an endoscopic ultrasonic diagnostic treatment apparatus according to a second embodiment of the present invention;

[0019] FIG. **10** is a block diagram showing a configuration example of one form of an ultrasonic wave control unit and its associated components in the endoscopic ultrasonic diagnostic treatment apparatus according to the second embodiment of the present invention;

[0020] FIG. **11** is a schematic diagram illustrating an image acquired by the ultrasonic apparatus according to the second embodiment of the present invention;

[0021] FIG. **12**A is a plane view showing an example of a cMUT array constituting an ultrasonic emitter according to a first modification of the second embodiment of the present invention;

[0022] FIG. **12**B is a sectional view showing an example of the cMUT array constituting an ultrasonic emitter according to the first modification of the second embodiment of the present invention;

[0023] FIG. **13** is a schematic diagram illustrating an image acquired by the ultrasonic apparatus according to the first modification of the second embodiment of the present invention;

[0024] FIG. **14** is a schematic diagram illustrating the relation between the phase and wave front of ultrasonic waves output by an ultrasonic emitter according to the second embodiment of the present invention;

[0025] FIG. **15** is a diagram showing a configuration example of a tip portion according to a second modification of the second embodiment of the present invention;

[0026] FIG. **16** is a block diagram showing a configuration example of an ultrasonic treatment apparatus according to a third embodiment of the present invention;

[0027] FIG. **17** is a schematic diagram illustrating radiation ranges of ultrasonic waves generated by an ultrasonic treatment apparatus according to a fourth embodiment of the present invention and also illustrating a difference tone generated in a region where the radiation ranges are superposed on each other;

[0028] FIG. **18** is a block diagram showing a configuration example of an ultrasonic treatment apparatus according to a fourth embodiment of the present invention;

[0029] FIGS. **19**A and **19**B are schematic diagrams illustrating the radiation ranges of the ultrasonic waves generated by the ultrasonic treatment apparatus according to the fourth embodiment of the present invention and also illustrating the region where the radiation ranges are superposed on each other and the difference tone is thus generated;

[0030] FIG. **20**A is a plane view showing an example of a cMUT array constituting an ultrasonic emitter according to a first modification of the fourth embodiment of the present invention;

[0031] FIG. **20**B is a sectional view showing an example of the cMUT array constituting an ultrasonic emitter according to the first modification of the fourth embodiment of the present invention;

[0032] FIGS. **21**A and **21**B are schematic diagrams illustrating radiation ranges of ultrasonic waves generated by an ultrasonic treatment apparatus according to the first modification of the fourth embodiment of the present invention and also illustrating a region where the radiation ranges are superposed on each other and a difference tone is thus generated;

[0033] FIG. **22** is schematic diagrams illustrating radiation ranges of ultrasonic waves generated by an ultrasonic treatment apparatus according to the first modification of the fourth embodiment of the present invention and also illustrating a region where the radiation ranges are superposed on each other and a difference tone is thus generated;

[0034] FIG. **23**A is a plane view showing an example of a focal interdigital transducer constituting an ultrasonic emitter according to a fifth embodiment of the present invention;

[0035] FIG. **23**B is a sectional view showing an example of the focal interdigital transducer constituting the ultrasonic emitter according to the fifth embodiment of the present invention;

[0036] FIG. **24** is a schematic diagram illustrating the position of the focus of ultrasonic waves generated by an ultrasonic treatment apparatus according to the fifth embodiment of the present invention;

[0037] FIG. **25** is a schematic diagram illustrating the focal positions of SAWs and BAWs generated by the ultrasonic treatment apparatus according to the fifth embodiment of the present invention;

[0038] FIG. **26** is a plane view showing an example of an interdigital transducer constituting an ultrasonic emitter according to a first modification of the fifth embodiment of the present invention;

[0039] FIG. **27** is a plane view showing an example of a focal interdigital transducer constituting an ultrasonic emitter according to a seventh embodiment of the present invention;

[0040] FIG. **28** is a schematic diagram illustrating the position of the focus of ultrasonic waves generated by an ultrasonic treatment apparatus according to the seventh embodiment of the present invention;

[0041] FIG. **29** is a plane view showing another example of a focal interdigital transducer constituting an ultrasonic emitter according to a seventh embodiment of the present invention;

[0042] FIG. **30** is a sectional view showing an example of an ultrasonic element constituting an ultrasonic emitter according to an eighth embodiment of the present invention;

[0043] FIGS. **31**A and **31**B are sectional views showing other examples of the ultrasonic element constituting the ultrasonic emitter according to the eighth embodiment of the present invention;

[0044] FIG. **32**A is a sectional view showing an example of an ultrasonic element constituting an ultrasonic emitter according to a tenth embodiment of the present invention;

[0045] FIG. **32**B is a plane view showing an example of the ultrasonic element constituting the ultrasonic emitter according to the tenth embodiment of the present invention;

[0046] FIG. **33**A is a sectional view showing another example of the ultrasonic element constituting the ultrasonic emitter according to the tenth embodiment of the present invention;

[0047] FIG. **33**B is a plane view showing another example of the ultrasonic element constituting the ultrasonic emitter according to the tenth embodiment of the present invention; and

[0048] FIGS. **34**A and **34**B are sectional views showing other examples of the ultrasonic element constituting the ultrasonic emitter according to the tenth embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

First Embodiment

[0049] A first embodiment of the present invention is described with reference to the drawings. An ultrasonic treatment apparatus according to the present embodiment is used for a treatment, for example, by destroying cells or by heating and coagulating a tissue. To this end, the ultrasonic treatment apparatus applies ultrasonic waves having a desired frequency to a target position. For example, to destroy cells, ultrasonic waves are directly applied to the cells so that the cells can be destroyed by the energy of the ultrasonic waves. Otherwise, microbubbles used as, for example, an ultrasonic contrast agent are provided to a part to be irradiated with ultrasonic waves, and the microbubbles are burst by ultrasonic irradiation. Thus, the cells can be destroyed by cavitation energy generated at the burst of the microbubbles.

[0050] A rough configuration of the ultrasonic treatment apparatus according to the present embodiment is shown in FIG. **1**. This ultrasonic treatment apparatus has a tip portion **100**, an ultrasonic treatment apparatus controller **200** and an input unit **250**. The tip portion **100** is, for example, cylindrically shaped. An ultrasonic wave emitter **110** which is a sound source of ultrasonic waves emitted by the ultrasonic treatment apparatus is disposed in a part of the circumferential surface of the tip portion **100**. The ultrasonic treatment apparatus controller **200** has a drive parameter setter **210**, an output information storage **215**, a drive controller **220**, a first signal generator **232**, a second signal generator **234** and an adder **236**.

[0051] The input unit **250** receives an operator instruction on, for example, an ultrasonic wave irradiation target position and the strength of ultrasonic waves to be radiated. The input unit **250** outputs the input operator instruction to the drive parameter setter **210**. On the basis of the information input from the input unit **250**, the drive parameter setter **210** reads frequency information from the output information storage **215**. On the basis of the frequency information, the drive parameter setter **210** determines the frequency, amplitude and initial phase of the ultrasonic waves to be emitted from the ultrasonic wave emitter **110**. The drive parameter setter **210**

outputs the determined frequency, amplitude and initial phase of the ultrasonic waves to the drive controller **220**.

[0052] The frequency information described later and the like are stored in the output information storage **215**. At the request of the drive parameter setter **210**, the output information storage **215** outputs the stored frequency information to the drive parameter setter **210**. On the basis of the frequency, amplitude and initial phase of the ultrasonic waves input from the drive parameter setter **210**, the drive controller **220** outputs an instruction to the first signal generator **232** and the second signal generator **234** to generate signals corresponding to the frequency, amplitude and initial phase of the ultrasonic waves.

[0053] On the basis of the instruction input from the drive controller **220** to generate ultrasonic signals, the first signal generator **232** and the second signal generator **234** respectively generate signals and output the signals to the adder **236**. The adder **236** adds together the signals input from the first signal generator **232** and the second signal generator **234**, and outputs a resultant drive signal to the ultrasonic wave emitter **110**. The adder **236** may be, for example, a general adding circuit using an operational amplifier. The signals having different frequencies can be superposed by the adder **236**, and the sound source can be driven by the resultant drive signals.

[0054] For example, the ultrasonic wave emitter **110** functions as a sound source for emitting finite amplitude acoustic waves including a first signal frequency and a second signal frequency. For example, the drive parameter setter **210** functions as a frequency setter for setting the first signal frequency and the second signal frequency in accordance with a target position of a treatment object with respect to the sound source. For example, the first signal generator **232**, the second signal generator **234** and the adder **236** function as drive signal generators configured to generate a drive signal and to drive the sound source, the drive signal being adapted to emit, to the sound source. For example, the output information storage **215** functions as a frequency information storage for storing information that associates the target position with the first signal frequency and the second signal frequency. For example, the input unit **250** functions as a position information input unit for inputting the target position. For example, the first signal generator **232** and the second signal generator **234** function as signal generators which generate a first drive signal having the first signal frequency and a second drive signal having the second signal frequency. For example, the adder **236** functions as an adder which adds the first drive signal and the second drive signal together to generate an additional drive signal.

[0055] The ultrasonic wave emitter **110** according to the present embodiment is described. The ultrasonic wave emitter **110** according to the present embodiment is, as shown in its plane view of FIG. **2**, a cMUT array **320** in which capacitive micromachined ultrasonic transducers (cMUTs) **310** are arrayed.

[0056] One cMUT **310** has, for example, a structure shown in a sectional view of FIG. **3**A and in a plane view of FIG. **3**B. The cMUT **310** is formed on a bottom substrate **311** made of, for example, silicon. A bottom electrode **312** made of, for example, Pt/Ti is formed on the bottom substrate **311**. The material of the bottom electrode **312** is not exclusively Pt/Ti and may be, for example, Au/Cr, Mo, W, phosphor bronze or Al. A dielectric film **313** made of, for example, $SrTiO_3$ is formed on the bottom electrode **312**. The material of the dielectric film **313** is not exclusively $SrTiO_3$ and can be a material having a high dielectric constant such as $BaTiO_3$, barium strontium titanate, tantalum pentoxide, niobia-stabilized tantalum pentoxide, aluminum oxide or TiO_2. This dielectric film **313** functions to increase a capacitance between a top electrode **317** and the bottom electrode **312** across a gap **314** described later.

[0057] A membrane supporter **315** made of, for example, SiN is present on the dielectric film **313** to have the cylindrical gap **314**. A membrane **316** made of, for example, SiN is formed over the gap **314** and the membrane supporter **315**. The top electrode **317** made of, for example, Pt/Ti as the bottom electrode **312** is formed on the membrane **316**.

[0058] A convex head **318** having a smaller diameter than the gap **314** is provided on the top electrode **317**. The head **318** is made of, for example, tetraethoxysilane (TEOS). The head **318** is thicker than the membrane **316** as a result of a semiconductor process. The material of the head **318** is not exclusively TEOS and can be some other material often used in the semiconductor process, such as SiN, SiO_2 or polyimide. Moreover, the head **318** may be a multilayer film of multiple materials.

[0059] In the cMUT **310** having such a configuration, when a voltage is applied across the top electrode **317** and the bottom electrode **312**, an attractive force acts between these electrodes. When the application of the voltage is stopped, an original state is restored. The membrane **316** and the head **318** formed thereon are vibrated by periodical voltage applications. As a result, ultrasonic waves having a finite amplitude are radiated from the cMUT **310**. By varying the frequency of the voltage applied across the top electrode **317** and the bottom electrode **312**, the cMUT **310** can output ultrasonic waves having various frequencies.

[0060] In the cMUT **310**, the part of the membrane **316** that lies over the gap **314** is relatively soft, and the top electrode **317** and the head **318** are relatively rigid. Therefore, when the membrane **316**, the top electrode **317** and the head **318** are taken as a whole, the place where the head **318** is located is relatively rigid, and the part therearound is relatively soft. Thus, the direction of the vibration and displacement of the membrane **316** during the application of the voltage across the bottom electrode **312** and the top electrode **317** is unified to the direction of a normal to the top surface of the convex portion of the head **318**. That is, while the membrane of the cMUT which does not include the head **318** vibrates in a bending manner, the membrane **316** of the cMUT **310** which includes the head **318** makes one-direction vibrations similar to thickness longitudinal vibrations. That is, the part of the top electrode **317** and the head **318** thereon can make vibrations similar to piston vibrations. As a result, according to this cMUT **310**, the directivity of emitted ultrasonic waves increases, and a high sound pressure effect can be obtained at the target position. Moreover, such a configuration can reduce unnecessary vibrations such as harmonic vibrations generated due to bending vibration of the membrane **316**.

[0061] The frequency characteristics of the cMUT **310** having the configuration described above are shown in FIG. **4**. As shown in the graph, the cMUT **310** has a stable output over a wide frequency range around a center frequency indicated by a dashed-dotted line. The center frequency ranges is designed to from, for example, more than ten MHz to several ten MHz, and its band is designed to be, for example, 50 to 100%. The cMUT **310** is also characterized by reduced device-to-device variation owing to the stabilization of its manufacturing process.

[0062] As shown in FIG. 5, the head **318** may be sloped. When the head **318** is thus sloped, ultrasonic waves are emitted in the direction of a normal to the slope, i.e., in a direction diagonal to the bottom substrate **311**.

[0063] The shape of the gap **314** in the cMUT **310** may be modified as shown in FIG. 6. That is, the cross-sectional areas of the surfaces parallel to the surface of the bottom substrate **311** on the bottom electrode **312** side and the top electrode **317** side may be different. Such a shape enables the band of output ultrasonic waves to be broader than when the gap **314** has a cylindrical shape as in the cMUT shown in FIG. 3.

[0064] The cMUT **310** may have some other polygonal planar shape such as a hexagonal planar shape shown in FIG. 7 instead of the above-mentioned quadrangular planar shape, and such cMUTs **310** may be arrayed to form the cMUT array **320**. The planar shape of the head **318** is not exclusively circular either.

[0065] The cMUT array **320** is an array of a great number of cMUTs **310**, and the bottom electrodes **312** of the respective cMUTs **310** are electrically connected to one another. The top electrodes **317** are also connected to one another. Thus, all of the cMUTs **310** vibrate at the same time. The ultrasonic wave emitter **110** having the cMUT array **320** comprising such cMUTs **310** is driven by the drive signal input from the adder **236** and outputs ultrasonic waves.

[0066] The radiation of ultrasonic waves to a target part by the ultrasonic treatment apparatus according to the present embodiment is described. One use of the ultrasonic treatment apparatus is, for example, to destroy cells by ultrasonic irradiation. For example, it is known that if microbubbles are provided to a part in which cells should be destroyed and the microbubbles are burst by ultrasonic irradiation, surrounding cells can be efficiently destroyed by cavitation energy generated by the burst of the microbubbles. In bursting the microbubbles, the efficiency of bursting the microbubbles is improved if the frequency of ultrasonic waves to be radiated is set at a value close to the resonance frequency of the microbubbles. For example, when a commercially available ultrasonic contrast agent is used as the microbubbles, the frequency of ultrasonic waves is appropriately about 1 to 2 MHz.

[0067] In general, ultrasonic waves of a higher frequency propagating through a substance are damped more. When the cMUT **310** is used as described above, the frequency of ultrasonic waves to be emitted can be changed. Thus, when an optimum frequency is selected in accordance with the depth of the target position to be irradiated with ultrasonic waves, the ultrasonic waves can be efficiently propagated to the target position.

[0068] In view of the circumstances, the frequency of ultrasonic waves to be emitted is considered as below in the ultrasonic treatment apparatus according to the present embodiment. For example, the frequency of the signal generated by the first signal generator **232** is f_1, the angular frequency thereof is ω_1, and the amplitude thereof is A. The frequency of the signal generated by the second signal generator **234** is f_2, the angular frequency thereof is ω_2, and the amplitude thereof is A. Here, the relation between f_1 and ω_1 and the relation between f_2 and ω_2 are as below.

$$\omega_1 = 2PIf_1$$

$$\omega_2 = 2PIf_2$$

[0069] The signal generated by the first signal generator **232** and the signal generated by the second signal generator **234** are input to the adder **236**, and the adder **236** adds these signals together. In this example, if the initial phase of the signal generated by the first signal generator **232** is coincident with the initial phase of the signal generated by the second signal generator **234**, an additional signal x(t) generated by the adder **236** is represented by Equation (1).

$$\begin{aligned} x(t) &= A\cos(\omega_1 t) + A\cos(\omega_2 t) \\ &= 2A\cos\frac{\omega_1 + \omega_2}{2}t\cos\frac{\omega_1 - \omega_2}{2}t \end{aligned} \tag{1}$$

[0070] Here, $x(t)=2A\cos(((\omega_1+\omega_2)/2)t)$ is referred to as carrier waves, and $x(t)=\cos(((\omega_1-\omega_2)t)$ is referred to as modulated waves. When the ultrasonic waves generated by the ultrasonic wave emitter **110** are applied to a subject in accordance with the additional signal x(t) represented by Equation (1), the ultrasonic waves having the frequency of the modulated waves are propagated by the ultrasonic waves having the frequency of the carrier waves. Thus, in order to apply ultrasonic waves of 1 to 2 MHz to the target position to burst the microbubbles as described above, f_1 and f_2 can be determined so that the frequency $\Delta f=|f_1-f_2|=(|\omega_1-\omega_2|)/2PI$ of the modulated waves may be 1 to 2 MHz.

[0071] As described above, ultrasonic waves of a higher frequency propagating through a substance are damped more. Thus, when the target position is far (deep) from the ultrasonic wave emitter **110** which is the source of the ultrasonic waves, f_1 and f_2 can be determined so that the frequency $(f_1+f_2)=(\omega_1+\omega_2)/2PI$ of the carrier waves may be low. When the target position is close (shallow) to the ultrasonic wave emitter **110**, f_1 and f_2 can be determined so that the frequency $(f_1+f_2)=(\omega_1+\omega_2)/2PI$ of the carrier waves may be high. The frequency of the carrier waves is desirably determined on the basis of the distance from the ultrasonic wave emitter **110** to the target position and on the basis of, for example, the ultrasonic wave absorption coefficient of the substance present between the ultrasonic wave emitter **110** and the target position.

[0072] For example, ultrasonic waves generated by the ultrasonic wave emitter **110** in accordance with the additional signal x(t) represented by Equation (1) are radiated. In this case, owing to the nonlinearity of a medium that conveys acoustic waves, an effect equivalent to generating the modulated waves having the frequency $\Delta f=|f_1-f_2|$ at the target position can be obtained. Such an effect is referred to as a self-demodulation effect. This self-demodulation effect is one of the important points of the present embodiment. If f_1 and f_2 that simultaneously satisfy the frequency of the modulated waves and the frequency of the carrier waves are determined, the ultrasonic treatment apparatus can apply ultrasonic waves having a desired frequency to the target position regardless of the difference of the depth of the target position. In the present embodiment, the drive parameter setter **210** determines the values of f_1 and f_2.

[0073] Equation (1) used in the above explanation is one example. It is possible to use other additional signals which are generated by using the signals output from the first signal generator **232** and the second signal generator **234** and which are the product of the carrier waves and the modulated waves. For example, an amplitude A_1 of the signal generated by the first signal generator **232** may be different from an amplitude A_2 of the signal generated by the second signal generator **234**.

Moreover, there may be a difference between the initial phases of the signals generated by the first signal generator **232** and the second signal generator **234**.

[0074] Now, the operation of the ultrasonic treatment apparatus according to the present embodiment is described. When this ultrasonic treatment apparatus is used, the ultrasonic wave emitter **110** of the tip portion **100** is brought into contact with a subject (sound propagating medium) to be irradiated with ultrasonic waves. There may be an acoustic matching layer for matching acoustic impedance between the ultrasonic wave emitter **110** and the subject, or the ultrasonic wave emitter **110** and the subject may be in direct contact. As the acoustic matching layer, it is possible to use, for example, a water bag containing deaerated water, or a sound matching material made of a resin or jellylike substance generally used in an ultrasonic diagnostic apparatus or ultrasonic treatment apparatus.

[0075] The ultrasonic treatment apparatus generates ultrasonic waves in accordance with an operator instruction input from the input unit **250** while the ultrasonic wave emitter **110** is in contact with the subject. The operator can use the input unit **250** to designate an ultrasonic wave irradiation target position. In this case, the drive parameter setter **210** of the ultrasonic treatment apparatus controller **200** first determines frequencies of the carrier waves and the modulated waves as described above in accordance with a target position and an object input from the input unit **250** and designated by the operator. The drive parameter setter **210** then determines the frequency f_1, amplitude A_1 and initial phase θ_1 of the signal generated by the first signal generator **232** and the frequency f_2, amplitude A_2 and initial phase θ_2 of the signal generated by the second signal generator **234** to correspond to the determined carrier waves and modulated waves. Here, the drive parameter setter **210** uses the frequency information stored in the output information storage **215**.

[0076] Tables which are prepared for $\Delta f=|f_1-f_2|$ and which contain information on combinations of f_1 and f_2 corresponding to depths X of the target position, for example, as schematically shown in FIG. **8** are stored in the output information storage **215**. The drive parameter setter **210** reads a necessary table from the output information storage **215** in accordance with the target position and object, and determines a combination of f_1 and f_2 on the basis of this table. It should be understood that the tables shown in FIG. **8** are illustrative only and any table that indicates a combination of f_1 and f_2 corresponding to the depth X of the target position may be used. Moreover, some or all of the relations between X, f_1 and f_2 may be represented by functions, and the drive parameter setter **210** may perform a calculation on the basis of the functions.

[0077] The combinations of f_1 and f_2 corresponding to the depth X of the target position are previously stored in the output information storage **215**, so that the drive parameter setter **210** can rapidly determine a combination of f_1 and f_2 in accordance with the target position and object.

[0078] Tables concerning the amplitude A_1 and initial phase θ_1 of the ultrasonic waves generated by the first signal generator **232** and the amplitude A_2 and initial phase θ_2 of the ultrasonic waves generated by the second signal generator **234** that are adapted to use are also stored in the output information storage **215**.

[0079] The drive parameter setter **210** outputs the determined f_1, f_2, A_1, A_2, θ_1 and θ_2 to the drive controller **220**. The drive controller **220** instructs the first signal generator **232** to output a signal of the frequency f_1, amplitude A_1 and initial phase θ_1, on the basis of the value input from the drive parameter setter **210**. The drive controller **220** also instructs the second signal generator **234** to output a signal of the frequency f_2, amplitude A_2 and initial phase θ_2.

[0080] The first signal generator **232** and the second signal generator **234** respectively generate signals on the basis of the instructions input from the drive controller **220** to generate ultrasonic waves. The first signal generator **232** and the second signal generator **234** respectively output the generated signals to the adder **236**. The adder **236** adds together the signals input from the first signal generator **232** and the second signal generator **234**, and outputs, to the ultrasonic wave emitter **110**, a drive signal which is the additional signal represented by, for example, Equation (1).

[0081] Each of the cMUTs **310** constituting the cMUT array **320** of the ultrasonic wave emitter **110** vibrates the head **318** to emit ultrasonic waves in response to the drive signal input from the adder **236**. As a result, the ultrasonic waves having the frequency $\Delta f=|f_1-f_2|$ to be self-demodulated at the target position as described above propagate through the subject.

[0082] The following advantages are obtained by the ultrasonic treatment apparatus according to the present embodiment. Even if the ultrasonic wave emitter **110** is used which has to have a high frequency of the ultrasonic waves to be output, for example, a center frequency ranging from more than ten MHz to several ten MHz due to the characteristics of the cMUT and element size reduction, it is possible to radiate ultrasonic waves of, for example, 1 to 2 MHz which is the resonance frequency of the microbubbles. This ultrasonic treatment apparatus can radiate ultrasonic waves having a frequency proper for the object regardless of the configuration of the ultrasonic wave emitter **110**. A frequency of the carrier waves is properly selected in such a manner as to take the damping of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use of the high-frequency ultrasonic waves advantageously allows for a sharper beam pattern.

Second Embodiment

[0083] A second embodiment of the present invention is described with reference to the drawings. Here, the difference between the second embodiment and the first embodiment is described, and the same parts as those in the first embodiment are provided with the same reference numbers and are not described. The present embodiment concerns an endoscopic ultrasonic diagnostic treatment apparatus that has the ultrasonic treatment apparatus according to the first embodiment.

[0084] An endoscopic ultrasonic diagnostic treatment apparatus **400** according to the present embodiment mainly comprises an ultrasonic device **410** and an endoscopic device **460**, as shown in FIG. **9**. The ultrasonic device **410** has an ultrasonic probe **420** equipped with an elongate probe insertion tube **422**. As shown in FIG. **9**, the ultrasonic probe **420** comprises the tip portion **100** of the ultrasonic treatment apparatus according to the first embodiment. The ultrasonic probe **420** is inserted into a body cavity, and emits ultrasonic waves from the ultrasonic wave emitter **110** which is disposed in the tip portion **100** and which is not shown in FIG. **9**. The ultrasonic probe **420** ultrasonically diagnoses and ultrasonically treats a desired living tissue in the body cavity by the emission of the ultrasonic waves. As has been described in the first embodiment, the ultrasonic wave emitter **110** performs a treatment to radiate ultrasonic waves to a target position and destroy cells at the target position by the energy of the ultrasonic waves. In addition, the ultrasonic device **410** has a function of ultrasonically diagnosing, before, after and during a treatment operation, a living tissue located in the vicinity of the target position to be treated.

[0085] The ultrasonic probe **420** is connected to an ultrasonic wave control unit **440** via a probe connecting unit **430**. The ultrasonic probe **420** and the probe connecting unit **430** are removably connected to each other by a connecting portion **424** provided at the proximal end of the ultrasonic probe **420** and by a coupling portion **432** of the probe connecting unit **430**. The probe connecting unit **430** and the ultrasonic wave control unit **440** are connected to each other by a connector **434** of the probe connecting unit **430**. The ultrasonic wave control unit **440** is a part which includes the ultrasonic treatment apparatus controller **200** in the first embodiment and which controls the ultrasonic probe **420**.

[0086] The ultrasonic wave control unit **440** generates a video signal on the basis of the signal obtained by the ultrasonic probe **420**. The ultrasonic device **410** has an ultrasonic image display unit **450** for displaying an ultrasonic tomogram in accordance with the video signal generated by the ultrasonic wave control unit **440**. The ultrasonic device **410** also has an input unit **455** for receiving operator inputs.

[0087] The endoscopic device **460** has an electronic endoscope **470** including an imaging device therein, a light source unit **492** for supplying an illumination light flux to the electronic endoscope **470**, a video processor **494** and an endoscopic image display unit **496**. The video processor **494** drives the unshown imaging device in the electronic endoscope **470**, and receives an electric signal transmitted from the imaging device and processes the signal in various forms to generate a video signal for displaying an endoscopic observation image. The video signal generated by the video processor **494** is input to the endoscopic image display unit **496**, and the endoscopic image display unit **496** displays the endoscopic observation image.

[0088] The electronic endoscope **470** mainly comprises an elongate insertion portion **472** to be inserted into the body cavity, an operation portion **474** disposed on the proximal side of the insertion portion **472**, and a universal cord **477** extending from the side part of the operation portion **474**.

[0089] An endoscope connector **478** to be connected to the light source unit **492** is provided at the end of the universal cord **477**. An electric connector **479** is provided on the side part of the endoscope connector **478**. A video cable **495** extending from the video processor **494** is connected to the electric connector **479**.

[0090] A curving portion **480** is provided on the tip side of the insertion portion **472**, and a hard portion **482** is further provided on the tip side of the curving portion **480**. A tip face **483** of the hard portion **482** is provided with an illumination light window **484** and an observation window **485** for direct-vision endoscopic observation, and a forceps exit **486**.

[0091] The operation portion **474** is provided with an angle knob **475**, operation switches **476**, and a treatment tool insertion port **481**. The angle knob **475** is used to control the curving operation of the curving portion **480** of the insertion portion **472**. The operation switches **476** are used to change display images displayed on a display screen of the endoscopic image display unit **496** and to indicate various operations such as a freeze operation or release operation. The treatment tool insertion port **481** is an introduction opening for, for example, a treatment tool to be introduced into the body cavity, and is in communication with the above-mentioned forceps exit **486**.

[0092] The ultrasonic wave control unit **440** is described. By combined with the endoscopic device **460**, the ultrasonic device **410** according to the present embodiment can be used for the treatment of irradiating the target position with ultrasonic waves in the body cavity as described in the first embodiment. Moreover, when the cMUT array **320** of the ultrasonic wave emitter **110** is used to emit and receive ultrasonic waves, the ultrasonic wave control unit **440** can also function as an ultrasonic image diagnostic apparatus.

[0093] As shown in FIG. **10**, the ultrasonic wave control unit **440** which controls the ultrasonic device **410** has the ultrasonic treatment apparatus controller **200** described in the first embodiment. The ultrasonic wave control unit **440** also has an ultrasonic device controller **441** for controlling the whole ultrasonic wave control unit **440**, a target position acquirer **442**, a rotation controller **443**, an image acquisition signal controller **445**, a receiver **446** and an image acquirer **447**.

[0094] The tip portion **100** can be rotated by an unshown rotation device to enable image acquisition and ultrasonic wave radiation in various directions within the body cavity. In order to control this rotation, the target position acquirer **442** acquires a direction to radiate ultrasonic waves from the ultrasonic device controller **441**. The target position acquirer **442** outputs, to the rotation controller **443**, information on the direction to radiate ultrasonic waves. The rotation controller **443** controls the operation of the unshown rotation device in accordance with the ultrasonic wave radiation direction input from the target position acquirer **442**. Further, the target position acquirer **442** acquires, from the ultrasonic device controller **441**, an ultrasonic wave irradiation target position for an ultrasonic treatment, and outputs the target position to the drive parameter setter **210**. The drive parameter setter **210** determines a frequency of ultrasonic waves to be radiated in accordance with the target position input from the target position acquirer **442**, as described in the first embodiment.

[0095] An ultrasonic image diagnosis is carried out in a generally known manner. Thus, the image acquisition signal controller **445** determines various parameters of an ultrasonic pulse suitable for the image diagnosis. The image acquisition signal controller **445** also controls the drive controller **220**. The image acquisition signal controller **445** outputs the determined value to the drive controller **220**. When ultrasonic waves having a pure sound are used, the drive controller **220** only uses the first signal generator **232**. The drive controller **220** outputs a signal generation instruction to the first signal generator **232** as in the first embodiment.

[0096] In the ultrasonic image diagnosis, each of the cMUTs **310** of the ultrasonic wave emitter **110** serves as a receiving element. The receiver **446** acquires the signal received by the cMUTs **310**. The receiver **446** outputs the acquired signal to the image acquirer **447**. The image acquirer **447** constructs an ultrasonic image in a generally known manner on the basis of the signal input from the receiver **446**. The image acquirer **447** outputs the constructed image to the ultrasonic device controller **441**.

[0097] The ultrasonic device controller **441** performs various calculations and controls the respective parts. The ultrasonic device controller **441** also receives an input from the input unit **455**. Moreover, the ultrasonic device controller **441** outputs the ultrasonic image input from the image acquirer **447** to the ultrasonic image display unit **450**. For example, the image acquisition signal controller **445** functions as an image acquisition signal setter which sets an image acquisition emission ultrasonic wave signal.

[0098] The operation of the endoscopic ultrasonic diagnostic treatment apparatus **400** according to the present embodiment is described. The endoscopic device **460** is a generally known endoscopic device and is not directly related to the present invention, and is therefore not described. The operator inserts the insertion portion **472** into the body cavity of the subject in a treatment, and brings the end of the insertion portion **472** to a position of the subject to be diagnosed or treated. In the treatment, microbubbles are administered.

[0099] The probe insertion tube **422** is inserted from the treatment tool insertion port **481** of the endoscopic device **460** and passed through the insertion portion **472**, and the tip portion **100** extends from the forceps exit **486**. At a position where a diagnosis or treatment is to be conducted, the ultrasonic device controller **441** instructs the respective parts to perform the ultrasonic image diagnosis.

[0100] The ultrasonic device controller **441** outputs, to the target position acquirer **442**, an angle at which an image is to be acquired. The target position acquirer **442** outputs, to the rotation controller **443**, the image acquisition angle input from the ultrasonic device controller **441**. The rotation controller **443** controls the unshown rotation device in accordance with the value input from the target position acquirer **442**. For example, when the acquisition of an image around the whole circumference of the tip portion **100** is requested, the rotation controller **443** controls the rotation device to, for example, continuously rotate the tip portion **100** at a regular velocity in consideration of the time required for the image acquisition. When the acquisition of an image, for example, within a certain angle of circumference rather than around the whole circumference of the tip portion **100** is requested, the rotation controller **443** may rotate the tip portion **100** repeatedly back and forth.

[0101] The ultrasonic device **410** acquires an ultrasonic image while rotating the tip portion **100** as described above. In accordance with the instruction from the ultrasonic device controller **441**, the image acquisition signal controller **445** controls the output of ultrasonic waves for acquiring an ultrasonic image. For example, the output ultrasonic waves are high-frequency pulse waves having a frequency of about 5 to 20 MHz and a pulse width of about several μ seconds. The image acquisition signal controller **445** outputs such information to the drive controller **220**.

[0102] In acquiring the ultrasonic image, the first signal generator **232** is only used for signal generation because the generated ultrasonic waves have a pure tone. The drive controller **220** outputs an instruction for the first signal generator **232** to generate a signal on the basis of the value input from the image acquisition signal controller **445**. The first signal generator **232** generates a signal in response to the instruction from the drive controller **220**, and outputs the signal to the adder **236**. The signal to be input to the adder **236** is the signal generated by the first signal generator **232** alone, so that the adder **236** outputs the signal input from the first signal generator **232** directly to the ultrasonic wave emitter **110**. In response to the signal input from the adder **236**, the ultrasonic wave emitter **110** vibrates the head **318** of the cMUT **310** to emit ultrasonic waves.

[0103] The ultrasonic waves emitted from the ultrasonic wave emitter **110** propagate through the subject. The propagated ultrasonic waves are reflected in accordance with the acoustic characteristics of the subject. The cMUT **310** of the ultrasonic wave emitter **110** captures the reflected waves by the head **318**. That is, the cMUT **310** is vibrated by the reflected waves. As a result, a voltage between the top electrode **317** and the bottom electrode **312** of the cMUT **310** is changed. The ultrasonic wave emitter **110** outputs this electric signal to the receiver **446**.

[0104] The receiver **446** acquires the electric signal from the ultrasonic wave emitter **110**, and outputs the electric signal to the image acquirer **447**. The image acquirer **447** constructs an image of the inside of the subject in a generally known manner on the basis of the signal input from the receiver **446**. An example of the constructed image is schematically represented in FIG. **11**. In the example of FIG. **11**, the internal structure of the subject in the whole circumferential direction of the tip portion **100** is observed. Here, a center **810** cannot be imaged because of the presence of the tip portion **100**. Moreover, an image acquirable range **820** exists depending on the range in which the emitted ultrasonic waves reach and the reflected waves can be detected. In this diagram, for example, the position of an object **830** can be indicated by a rotation angle θ based on an axis defined by the posture of the tip portion **100** and by a distance r from the center of the tip portion **100**.

[0105] The image acquirer **447** outputs the acquired image to the ultrasonic device controller **441**. The ultrasonic device controller **441** outputs the image input from the image acquirer **447** to the ultrasonic image display unit **450**. The ultrasonic image display unit **450** displays, for example, an ultrasonic image shown in FIG. **11** input from the ultrasonic device controller **441**.

[0106] The operator determines a target position to be treated while checking the image displayed on the ultrasonic image display unit **450**. The input unit **455** receives the input of the treatment target position determined by the operator. The operator also determines a frequency of ultrasonic waves to be radiated, in accordance with the treatment target. The input unit **455** receives the frequency of the ultrasonic waves to be radiated to the treatment target determined by the operator. Here, general input means such as a keyboard, mouse or joystick may be used as the input unit **455**.

[0107] The input unit **455** outputs the operator instruction to the ultrasonic device controller **441**. In accordance with the operator instruction input from the input unit **455**, the ultrasonic device controller **441** controls the ultrasonic wave emitter **110** to emit treatment ultrasonic waves. The ultrasonic device controller **441** outputs an instruction for the image acquisition signal controller **445** to stop the emission of the ultrasonic waves for acquiring an ultrasonic image. On the other hand, the ultrasonic device controller **441** outputs, to the target position acquirer **442**, the target position input from the operator.

[0108] In accordance with the target position input from the ultrasonic device controller **441**, the target position acquirer **442** outputs a desired rotation angle (value associated with θ in FIG. **11**) of the tip portion **100** to the rotation controller **443** in order to direct the ultrasonic wave emitter **110** to the target position. On the basis of the input from the target position acquirer **442**, the rotation controller **443** controls the rotation device, and rotates the tip portion **100** to direct the ultrasonic wave emitter **110** to the target position.

[0109] The target position acquirer **442** outputs, to the drive parameter setter **210**, the distance (r in FIG. **11**) of the target position from the ultrasonic wave emitter **110**. The ultrasonic device controller **441** outputs, to the drive parameter setter **210**, the frequency of the radiation ultrasonic waves input from the input unit **455**. On the basis of the target position input from the target position acquirer **442** and the frequency of the radiation ultrasonic waves input from the ultrasonic device controller **441**, the drive parameter setter **210** calculates the frequency of the ultrasonic waves to be output, as has been described in the first embodiment. The ultrasonic waves are then emitted as has been described in the first embodiment. As a result, the ultrasonic waves having the set frequency are propagated to the target position, and the desired ultrasonic waves are applied to the target position.

[0110] The tissue degenerated by the ultrasonic wave irradiation is lower in ultrasonic wave propagation efficiency than the tissue before ultrasonic wave irradiation. Therefore, it is preferable to radiate ultrasonic waves from far parts (the side far from the ultrasonic wave emitter **110**) to near parts (the side close to the ultrasonic wave emitter **110**) in order.

[0111] The endoscopic ultrasonic diagnostic treatment apparatus **400** may be configured so that the procedure of ultrasonic wave radiation from the far parts to the near parts may be performed regardless of the operator instruction. Control may be performed so that ultrasonic waves are radiated in order by a predetermined procedure within a desired ultrasonic wave radiation range designated by the operator. For such control, for example, the drive parameter setter **210** gradually changes the frequency of the carrier waves for the output ultrasonic waves in increments within the range designated by the operator.

[0112] The endoscopic ultrasonic diagnostic treatment apparatus **400** according to the present embodiment ensures that an image of the inside of the subject is acquired by the ultrasonic device **410**, and at the same time, the ultrasonic waves having the frequency of the set modulated waves can be applied to various target positions. That is, the rotation angle of the tip portion **100** can be controlled in accordance with the target position to be irradiated with ultrasonic waves. Moreover, a frequency of the carrier waves is properly selected in such a manner as to take the damping of the ultrasonic waves into consideration, thereby ensuring that the ultrasonic waves having the set frequency can be applied to the target position. For example, microbubble cavitation can be highly efficiently generated, thereby ensuring that cells can be destroyed by low-energy ultrasonic waves.

[0113] Furthermore, according to the endoscopic ultrasonic diagnostic treatment apparatus **400** of the present embodiment, the tip portion **100** is driven as has been described in the first embodiment. Thus, the same ultrasonic wave generating element can be used to generate ultrasonic waves having an image acquisition frequency of about 5 to 20 MHz and ultrasonic waves of, for example, 1 to 2 MHz which is the resonance frequency of the microbubbles.

First Modification of Second Embodiment

[0114] A first modification of the second embodiment is described with reference to the drawings. Here, the difference between the present modification and the second embodiment is described, and the same parts as those in the second embodiment are provided with the same reference numbers and are not described. The tip portion **100** according to the second embodiment is configured so that the ultrasonic wave emitter **110** is circumferentially rotated by the rotation controller **443** and the unshown rotation device.

[0115] In contrast, according to this modification, an ultrasonic wave emitter **110** does not physically rotate but is configured to be able to change the radiation direction of ultrasonic waves. That is, an enlarged plane view of part of a cMUT array **320** is shown in FIG. **12**A, and a sectional view through **12**B-**12**B in FIG. **12**A is shown in FIG. **12**B. As shown in FIG. **12**B, heads **318** of cMUTs **310** constituting the cMUT array **320** have different slopes depending on the position in the cMUT array **320**. The heads **318** having the same slope are grouped together. The cMUT array **320** is configured to be able to control a voltage difference between a top electrode **317** and a bottom electrode **312** of the cMUT **310** on a group basis. Thus, the emission direction of ultrasonic waves can be changed by selecting a group of the cMUTs **310** to emit ultrasonic waves. Such a change of the emission direction of ultrasonic waves can also be applied to ultrasonic waves for acquiring an ultrasonic image and ultrasonic waves for treatment. A schematic diagram of an ultrasonic image obtained by the endoscopic ultrasonic diagnostic treatment apparatus **400** having such a configuration is shown in FIG. **13**. There is no essential difference between the image obtained by this modification and the image obtained by the second embodiment.

[0116] According to the endoscopic ultrasonic diagnostic treatment apparatus **400** having such a configuration, advantages similar to the advantages of the endoscopic ultrasonic diagnostic treatment apparatus **400** according to the second embodiment can be obtained.

[0117] Furthermore, the endoscopic ultrasonic diagnostic treatment apparatus **400** may be configured to use the ultrasonic wave emitter **110** in which all of the heads **318** have the same slope as in the second embodiment so that the radiation direction of ultrasonic waves is changed by a phased array. The phased array is briefly described. The relation between the phase and wave front of emitted ultrasonic waves is shown in FIG. **14**. In this diagram, a middle row in the right and left parts schematically shows the cMUT array **320**. Here, squares indicate the cMUTs **310** that constitute the cMUT array **320**. In the lower row of this diagram, the phases of the ultrasonic waves emitted from the cMUTs **310** are schematically shown by solid lines. In the upper row of this diagram, the wave fronts of the emitted ultrasonic waves are schematically shown by broken lines. As shown, the ultrasonic waves emitted from the respective cMUTs **310** gradually come out of phase in accordance with the positions of the cMUTs **310** in the cMUT array **320**, so that the traveling directions of the emitted ultrasonic waves are different. In FIG. **14**, the left side shows that the ultrasonic waves are traveling leftward in the diagram, and the right side shows that the ultrasonic waves are traveling rightward in the diagram.

[0118] In this modification, the adder **236** adds together signals input from a first signal generator **232** and a second signal generator **234**, and then adds a phase difference to the additional signal in accordance with the positions of the cMUTs **310** in the cMUT array **320**. Further, the adder **236** outputs, to the cMUTs **310** in the cMUT array **320**, a drive signal which is the additional signal to which the phase difference is added. Thus, the radiation direction of emitted ultrasonic waves can also be changed by using the phased array.

[0119] Such a configuration can also provide advantages similar to the advantages of the endoscopic ultrasonic diagnostic treatment apparatus **400** according to the second embodiment. A tip portion **100** and ultrasonic treatment apparatus controller **200** according to this modification are not exclusively incorporated in the endoscopic ultrasonic diagnostic treatment apparatus **400**, and an ultrasonic treatment apparatus can be independently used as has been described in the first embodiment.

Second Modification of Second Embodiment

[0120] A second modification of the second embodiment is described with reference to the drawings. Here, the difference between the present modification and the second embodiment is described, and the same parts as those in the second embodiment are provided with the same reference numbers and are not described. The tip portion **100** according to the second embodiment is cylindrical, and the ultrasonic wave emitter **110** is disposed in a part of the circumferential surface of the tip portion **100**. In contrast, in a tip portion **100** according to this modification, an ultrasonic wave emitter **110** is disposed in the distal face of the tip portion **100**, as shown in FIG. **15**.

[0121] As a result of the modified shape of the tip portion **100**, an endoscopic ultrasonic diagnostic treatment apparatus **400** according to the present modification does not have the rotation controller **443** and the unshown rotation device. Instead, the endoscopic ultrasonic diagnostic treatment apparatus **400** may be provided with a known mechanism for changing the radiation angle of ultrasonic waves with respect to the central axis direction of the tip portion **100**. For example, the endoscopic ultrasonic diagnostic treatment apparatus **400** can have a mechanism for physically changing the direction of the ultrasonic wave radiation surface of a cMUT array **320**. Moreover, the endoscopic ultrasonic diagnostic treatment apparatus **400** can be configured to change the radiation direction of ultrasonic waves by varying the angle of a head **318** of the cMUT **310** as in the first modification of the second embodiment. The endoscopic ultrasonic diagnostic treatment apparatus **400** can also be configured so that the direction of ultrasonic waves emitted from the cMUT array **320** may be changed by a phased array. Each case is essentially not different from the second embodiment. According to the endoscopic ultrasonic diagnostic treatment apparatus **400** having such a configuration, advantages similar to the advantages of the endoscopic ultrasonic diagnostic treatment apparatus **400** according to the second embodiment can also be obtained.

[0122] The endoscopic ultrasonic diagnostic treatment apparatus is described by way of example in the second embodiment. However, if the ultrasonic probe **420** and the endoscopic device **460** are modified, a laparoscope, an intraoperative apparatus, an extracorporeal apparatus and other forms of apparatuses can be produced using a similar configuration.

Third Embodiment

[0123] A third embodiment of the present invention is described with reference to the drawings. Here, the difference between the third embodiment and the first embodiment is described, and the same parts as those in the first embodiment are provided with the same reference numbers and are not described. In the ultrasonic treatment apparatus according to the first embodiment, the signals generated by the first signal generator **232** and the second signal generator **234** are added together by the adder **236**, and the signal represented by Equation (1) is thereby generated. In contrast, in the present embodiment, a signal similar to that in the first embodiment is generated by amplitude modulation.

[0124] In an ultrasonic treatment apparatus according to the present embodiment, an ultrasonic treatment apparatus controller **200** has a drive parameter setter **210**, an output information storage **215**, a drive controller **220**, a carrier wave signal generator **242** and a modulator **244**, as shown in FIG. **16**. Here, as in the first embodiment, the drive parameter setter **210** reads frequency information from the output information storage **215** on the basis of an input from an input unit **250**, calculates various parameters of ultrasonic waves emitted from an ultrasonic wave emitter **110**, and outputs the parameters to the drive controller **220**.

[0125] On the basis of the parameters input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for the carrier wave signal generator **242** to generate a signal, and outputs an instruction for the modulator **244** to modulate the signal. In accordance with the instruction input from the drive controller **220**, the carrier wave signal generator **242** generates a carrier wave signal, and outputs the carrier wave signal to the modulator **244**. In accordance with the instruction input from the drive controller **220**, the modulator **244** modulates the carrier wave signal input from the carrier wave signal generator **242**. The modulator **244** outputs, to the ultrasonic wave emitter **110**, a drive signal which is the signal generated by the modulation. The modulator **244** is a general modulation circuit. For example, the carrier wave signal generator **242** and the modulator **244** function as drive signal generators for generating the drive signal by amplitude modulation.

[0126] The operation of the ultrasonic treatment apparatus according to the present embodiment is described. For example, a frequency f_m of modulated waves is stored in the output information storage **215** in association with an object to be irradiated with ultrasonic waves. A frequency f_c of carrier waves is stored in the output information storage **215** in association with the distance (depth) between the ultrasonic wave emitter **110** and the object to be irradiated with ultrasonic waves. In addition, information regarding the ultrasonic waves emitted by the ultrasonic wave emitter **110**, such as the strength of the ultrasonic waves is stored in the output information storage **215**.

[0127] In accordance with an input from the input unit **250**, the drive parameter setter **210** reads the information stored in the output information storage **215**. On the basis of the read information, the drive parameter setter **210** determines a signal x(t) output by the modulator **244**, i.e., a signal for emitting ultrasonic waves from the ultrasonic wave emitter **110**, in accordance with the object to be irradiated with ultrasonic waves and the distance to the object. The signal x(t) output by the modulator **244** is represented by, for example, Equation (2).

$$x(t)=A\cos(\omega_c t)\cos(\omega_m t) \quad (2)$$

[0128] where $\omega_m=2PIf_m$, $\omega_c=2PIf_c$. As in Equation (1), in this example, $x(t)=A\cos(\omega_c t)$ corresponds to carrier waves, and $x(t)=\cos(\omega_m t)$ corresponds to modulated waves. The drive parameter setter **210** outputs, to the drive controller **220**, the determined signal for emitting ultrasonic waves from the ultrasonic wave emitter **110**, i.e., information on the signal x(t) output by the modulator **244**. For example, in order to burst microbubbles, f_m is about 1 to 2 MHz.

[0129] On the basis of the signal input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for the carrier wave signal generator **242** to generate a signal, and outputs an instruction for the modulator **244** to modulate the signal.

[0130] In accordance with the input from the drive controller **220**, the carrier wave signal generator **242** generates a signal. For example, in Equation (2), the carrier wave signal generator **242** generates a signal $x(t)=A\cos(\omega_c t)$ as carrier waves. The carrier wave signal generator **242** outputs the generated signal to the modulator **244**.

[0131] The carrier waves from the carrier wave signal generator **242** are input to the modulator **244**. On the basis of the input from the drive controller **220**, the modulator **244** generates a modulated wave signal, and modulates the carrier waves by this modulating signal. For example, in Equation (2), the modulator **244** generates a signal $x(t)=\cos(\omega_m t)$ as modulated waves, and modulates the carrier waves by this modulating signal. The modulator **244** outputs a resultant drive signal to the ultrasonic wave emitter **110**.

[0132] As in the first embodiment, when this ultrasonic treatment apparatus is used, the ultrasonic wave emitter **110** of the tip portion **100** is brought into contact with a subject (sound propagating medium) to be irradiated with ultrasonic waves. There may be an acoustic matching layer for matching acoustic impedance between the ultrasonic wave emitter **110** and the subject, or the ultrasonic wave emitter **110** and the subject may be in direct contact. Each of cMUTs **310** constituting a cMUT array **320** of the ultrasonic wave emitter **110** vibrates a head **318** in response to the drive signal input from the modulator **244**. As a result, ultrasonic waves represented by, for example, Equation (2) and corresponding to the signal x(t) output by the modulator **244** are emitted from the ultrasonic wave emitter **110**. The radiation of the ultrasonic waves is equal to the fact that ultrasonic waves having the frequency of the modulated waves are propagated to a target position by the carrier waves. That is, the ultrasonic waves having the frequency of the modulated waves are self-demodulated at the target position by radiation of the ultrasonic waves. As a result, the ultrasonic waves having the frequency of the modulated waves are applied to the target position.

[0133] According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**, as in the first embodiment. A frequency of the carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

Modification of Third Embodiment

[0134] As in the first modification of the second embodiment described with reference to FIG. **12**B, the ultrasonic treatment apparatus according to the third embodiment may be configured so that heads **318** of cMUTs **310** have different slopes. As in the first modification of the second embodiment described with reference to FIG. **14**, the ultrasonic treatment apparatus may be configured so that the emission direction of ultrasonic waves can be changed by a phased array. Moreover, the endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment may be configured by use of the ultrasonic treatment apparatus according to the present embodiment or the above-mentioned modifications. Such a modification can also provide advantages similar to the advantages described above.

Fourth Embodiment

[0135] A forth embodiment of the present invention is described with reference to the drawings. Here, the difference between the forth embodiment and the first embodiment is described, and the same parts as those in the first embodiment are provided with the same reference numbers and are not described. In the ultrasonic treatment apparatus according to the first embodiment, the adder **236** adds together the signal of the frequency f_1 generated by the first signal generator **232** and the signal of the frequency f_2 generated by the second signal generator **234**, thereby generating the signal represented by Equation (1).

[0136] In contrast, in the present embodiment, cMUTs **310** which are ultrasonic wave generating elements of a cMUT array **320** of an ultrasonic wave emitter **110** are separated into two groups. As shown in FIG. **17**, ultrasonic waves US**1** of the frequency f_1 are generated from a first cMUT array **322** which is a first group, and ultrasonic waves US**2** of the frequency f_2 are generated from a second cMUT array **324** which is a second group. As a result, in a space where both kinds of the ultrasonic waves are radiated, a harmonic or combination tone is generated by the nonlinearity of a medium that conveys acoustic waves, in a superposed space P (a shaded region in FIG. **17**) where the ultrasonic waves US**1** of the frequency f_1 and the ultrasonic waves US**2** of the frequency f_2 are superposed on each other. Thus, in the superposed space P, there is produced a condition substantially similar to the condition in which the ultrasonic waves generated by the signal x(t) represented by Equation (1) in the first embodiment are radiated. That is, ultrasonic waves having a frequency $\Delta f=|f_1-f_2|$ are generated in the superposed space P. Such an effect is referred to as a parametric effect.

[0137] The configuration of an ultrasonic treatment apparatus according to the present embodiment is shown in FIG. **18**. An ultrasonic treatment apparatus controller **200** of this ultrasonic treatment apparatus includes a drive parameter setter **210**, an output information storage **215**, a drive controller **220**, a first signal generator **232** and a second signal generator **234**, as in the first embodiment. The function of each component is similar to that in the first embodiment. However, in the present embodiment, the adder **236** that is present in the first embodiment is not provided. In the present embodiment, the first signal generator **232** outputs the generated signal of the frequency f_1 to the first cMUT array **322** of the ultrasonic wave emitter **110** as a drive signal. The second signal generator **234** outputs the generated signal of the frequency f_2 to the second cMUT array **324** of the ultrasonic wave emitter **110** as a drive signal.

[0138] In response to the drive signal input from the first signal generator **232**, each of the cMUTs **310** constituting the first cMUT array **322** vibrates the head **318** to radiate ultrasonic waves of the frequency f_1. In response to the drive signal input from the second signal generator **234**, each of the cMUTs **310** constituting the second signal generator **234** vibrates the head **318** to radiate ultrasonic waves of the frequency f_2. Among the cMUTs **310** constituting the cMUT array **320**, any of the cMUTs **310** can function as the first cMUT array **322**, and any of the cMUTs **310** can function as the second cMUT array **324**.

[0139] For example, the first cMUT array **322** functions as at least one ultrasonic wave emitter driven by a first drive signal. For example, the second cMUT array **324** functions as at least another ultrasonic wave emitter driven by a second drive signal.

[0140] When such a configuration is used in operation, the ultrasonic waves are propagated as in the schematic diagrams of FIGS. **19**A and **19**B. For example, the frequency f_1 of the ultrasonic waves US**1** emitted by the first cMUT array **322** is 6 MHz, and the frequency f_2 of the ultrasonic waves US**2** emitted by the second cMUT array **324** is 5 MHz. In consequence, the propagation region of the ultrasonic waves is as shown in FIG. **19**A. Here, a frequency Δf of the ultrasonic waves generated in the superposed space P is 1 MHz. On the other hand, for example, the frequency f_1 of ultrasonic waves US**1**' emitted by the first cMUT array **322** is 21 MHz, and the frequency f_2 of the ultrasonic waves US**2**' emitted by the second cMUT array **324** is 20 MHz. In consequence, the propagation region of the ultrasonic waves is as shown in FIG. **19**B because a higher frequency leads to more attenuating so that the range of the ultrasonic waves is smaller. In this case as well, the frequency Δf of the ultrasonic waves generated in a superposed space P' is 1 MHz. Thus, in each case, the ultrasonic waves of Δf=1 MHz are generated in the superposed space. On the other hand, the region where the ultrasonic waves of Δf=1 MHz are generated varies depending on the combination of the frequencies f_1 and f_2.

[0141] According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**, as in the first embodiment. A frequency of the carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

First Modification of Fourth Embodiment

[0142] A first modification of the forth embodiment is described with reference to the drawings. Here, the difference between the present modification and the forth embodiment is described, and the same parts as those in the forth embodiment are provided with the same reference numbers and are not described.

[0143] In the fourth embodiment, the ultrasonic wave emitting surfaces of the ultrasonic wave emitters **110** described with reference to FIG. **17** are parallel to each other. In contrast, the ultrasonic wave emitting surfaces of ultrasonic wave emitters **110** according to this modification are sloped, as shown in a plane view of FIG. **20**A and a sectional view of FIG. **20**B through **20**B-**20**B of FIG. **20**A. For example, as shown in FIG. **20**B, heads **318** of cMUTs **310** are designed to be differently sloped symmetrically with respect to a central line indicated by a dashed-dotted line. The slopes are angled to focus emitted ultrasonic waves.

[0144] Ultrasonic waves US**1** of a frequency f_1 emitted from first group ultrasonic wave generating elements and ultrasonic waves US**2** of a frequency f_2 emitted from second group ultrasonic wave generating elements are superposed on each other in a superposed space P. The superposed space P is larger as shown in FIG. **21**B when emitting surfaces are designed to be sloped as has been described with reference to FIGS. **20**A and **20**B than when emitting surfaces are parallel to one other as shown in FIG. **21**A. Consequently, this ultrasonic treatment apparatus can efficiently use the energy of emitted ultrasonic waves.

[0145] Among cMUTs **310**, any of the cMUTs **310** can serve as a first cMUT array **322**, and any of the cMUTs **310** can serve as a second cMUT array **324**. The operation is the same as that of the ultrasonic treatment apparatus according to the fourth embodiment. According to this modification, advantages similar to the advantages according to the fourth embodiment can also be obtained.

Second Modification of Fourth Embodiment

[0146] As in the first modification of the second embodiment described with reference to FIG. **12**B, the ultrasonic treatment apparatus according to the fourth embodiment may be configured so that the heads **318** of the cMUTs **310** are differently sloped to enable ultrasonic waves to be radiated in various directions. When the heads **318** of the cMUTs **310** are configured to be differently sloped, a superposed space P where the ultrasonic waves US**1** and the ultrasonic waves US**2** are superposed on each other can be formed at various positions by properly selecting the first group ultrasonic wave generating elements for emitting the ultrasonic waves US**1** of the frequency f_1 and the second group ultrasonic wave generating elements for emitting the ultrasonic waves US**2** of the frequency f_2.

[0147] For example, as schematically shown in FIG. **22**, ultrasonic waves US**1** are emitted from the cMUT **310** indicated by "1", and ultrasonic waves US**4** are emitted from the cMUT **310** indicated by "4", such that ultrasonic waves having a difference tone are generated in a superposed space P**14**. On the other hand, ultrasonic waves US**3** are emitted from the cMUT **310** indicated by "3", and ultrasonic waves US**5** are emitted from the cMUT **310** indicated by "5", such that ultrasonic waves having a difference tone are generated in a superposed space P**35**. Thus, the target position can be changed by selecting the first group ultrasonic wave generating elements and the second group ultrasonic wave generating elements.

[0148] As in the first modification of the second embodiment described with reference to FIG. **14**, the ultrasonic treatment apparatus may be configured so that the emission direction of ultrasonic waves can be changed by a phased array. Moreover, the endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment may be configured by use of the ultrasonic treatment apparatus according to the present embodiment or the above-mentioned modifications. Such a modification can also provide advantages similar to the advantages described above.

Fifth Embodiment

[0149] A fifth embodiment of the present invention is described with reference to the drawings. Here, the difference between the fifth embodiment and the first embodiment is described, and the same parts as those in the first embodiment are provided with the same reference numbers and are not described.

[0150] In the ultrasonic treatment apparatus according to the first embodiment, the cMUT array **320** is used as the ultrasonic wave emitter **110**. In contrast, a focal interdigital transducer (F-IDT) **510** is used as an ultrasonic wave emitter **110** of the ultrasonic treatment apparatus according to the present embodiment. In the interdigital transducer **510**, an arc-shaped interdigital electrode **512** is formed on a Y-cut Z-propagation lithium niobate ($LiNbO_3$) substrate **511**, as shown in a plane view of FIG. **23**A and a sectional view of FIG. **23**B. The operational principle of the IDT is described in "Maezawa and Kamakura (2009). Acoustic streaming generated by switching radiation modes for SAW device and its application to liquid mixing. Inst. Electron, Inform. Commun. Eng Tech. Rep., Vol. 109(17), 17-22," the entire contents of which are incorporated herein by reference. The configuration of the ultrasonic treatment apparatus according to the present embodiment is similar to the configuration according to the first embodiment described with reference to FIG. **1** except that the F-IDT is used as the ultrasonic wave emitter **110**.

[0151] The ultrasonic wave emitter **110** comprising the F-IDT **510** is in contact with a subject (sound propagating medium) in operation. When a voltage is applied to the interdigital electrode **512** of the F-IDT **510**, the interdigital electrode vibrates, and surface acoustic waves (SAWs) are generated on the surface of the lithium niobate substrate **511**. The SAWs propagate along the surface of the lithium niobate substrate **511**, and are then radiated to the subject. The frequency of the SAWs is about several ten MHz. As the interdigital electrode **512** is arc-shaped, the propagated ultrasonic waves are focused on a focus O as shown in FIG. **24**. That is, the energy of the ultrasonic waves can be concentrated on the focus O. Here, the focus O is at a position corresponding to the center of a sector form of the interdigital electrode **512**. An ultrasonic wave radiation angle θs with the normal to the surface of the lithium niobate substrate **511** where the interdigital electrode **512** is formed is determined by a ratio between the propagation velocity of the ultrasonic waves in the lithium niobate substrate **511** and the propagation velocity of the ultrasonic waves in the subject. There are a relatively small number of pairs, for example, several pairs to several ten pairs of engaged electrodes, so that an output frequency band is broader.

[0152] The F-IDT **510** which emits ultrasonic waves having a high frequency of about several ten MHz is used to apply, to a desired position (depth), ultrasonic waves of, for example, 1 to 2 MHz which is the resonance frequency of the microbubbles. Thus, in the present embodiment, the self-demodulation effect is used as in the first embodiment. Accordingly, an ultrasonic treatment apparatus controller **200** for controlling and driving the F-IDT **510** is the same as the ultrasonic treatment apparatus controller **200** according to the first embodiment.

[0153] The ultrasonic treatment apparatus controller **200** includes a drive parameter setter **210**, an output information storage **215**, a drive controller **220**, a first signal generator **232**, a second signal generator **234** and an adder **236**. In response to the operator instruction input from an input unit **250**, the drive parameter setter **210** of the ultrasonic treatment apparatus controller **200** determines frequencies of carrier waves and modulated waves in accordance with a target position and an object to be irradiated with ultrasonic waves. For the determined frequencies of the carrier waves and the modulated waves, the drive parameter setter **210** determines the frequency f_1, amplitude A_1 and initial phase θ_1 of a signal generated by the first signal generator **232** and the frequency f_2, amplitude A_2 and initial phase θ_2 of the signal generated by the second signal generator **234**. Here, the drive parameter setter **210** uses frequency information stored in the output information storage **215**, for example, shown in FIG. **8**. The drive parameter setter **210** outputs the determined f_1, f_2, A_1, A_2, θ_1 and θ_2 to the drive controller **220**.

[0154] On the basis of the value input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for the first signal generator **232** to generate a signal having the frequency f_1, amplitude A_1 and initial phase θ_1. The drive controller **220** also outputs an instruction for the second signal generator **234** to generate a signal having the frequency f_2, amplitude A_2 and initial phase θ_2. On the basis of the instructions input from the drive controller **220** to generate ultrasonic waves, the first signal generator **232** and the second signal generator **234** respectively generate signals and output the signals to the adder **236**. The adder **236** adds together the signals input from the first signal generator **232** and the second signal generator **234**, and outputs a drive signal represented by Equation (1) to the ultrasonic wave emitter **110**.

[0155] Consequently, this ultrasonic treatment apparatus can apply ultrasonic waves having a desired frequency to the target position as shown in FIG. **24** by the principle and operation similar to those described in the first embodiment. That is, when the drive signal is applied to the interdigital electrode **512** of the F-IDT **510**, the interdigital electrode vibrates, and SAWs are generated on the surface of the lithium niobate substrate **511**. The SAWs are radiated to the subject. The radiated ultrasonic waves focus on the focus O. If the focus O is set at the target position, self-demodulated ultrasonic waves are generated at the target position.

[0156] Furthermore, when driven at a frequency which is about 1.5 to 2 times the center frequency of the SAWs, the F-IDT **510** generates strong bulk acoustic waves (BAWs). While the SAWs propagate along the surface of the substrate and are applied to the subject, the BAWs propagate through the lithium niobate substrate **511** from the surface in which the interdigital electrode **512** is formed. The BAWs which have propagated through the lithium niobate substrate **511** are reflected on the rear side of the surface in which the interdigital electrode **512** is formed, and return to the surface in which the interdigital electrode **512** is formed. From this surface, ultrasonic waves are then radiated to the subject. In this case, an angle θ_B formed by the radiation direction of the ultrasonic waves with the normal to the lithium niobate substrate **511** is smaller than an angle θ_S formed by the radiation direction of the ultrasonic waves derived from the SAWs with the normal, as shown in FIG. **25**.

[0157] In the ultrasonic treatment apparatus according to the present embodiment, the drive parameter setter **210** properly selects a frequency input to the interdigital electrode **512**, so that the SAWs or BAWs can be generated. The BAWs can also be excited by raising or dropping a drive frequency with respect to the center frequency of the SAWs. In such a manner, the angle of the ultrasonic wave radiation to the subject, that is, the focal position can be changed as shown in FIG. **25**. Thus, this ultrasonic treatment apparatus is capable of changing the target position to be irradiated with ultrasonic waves.

[0158] Y-cut Z-propagation lithium niobate (YZ—$LiNbO_3$) is not exclusively used for the lithium niobate substrate **511**. For example, 128°-rotated Y-cut Z-propagation lithium niobate (128YX—$LiNbO_3$) may be used. It is known that both of the Y-cut Z-propagation and 128°-rotated Y-cut X-propagation provide sections that efficiently generate ultrasonic waves. If the SAWs and/or the BAWs can be generated, PZT or ZnO may be used instead of lithium niobate.

[0159] According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves of, for example, 1 to 2 MHz which is the resonance frequency of the microbubbles can be radiated even by the F-IDT having a high output frequency of several ten MHz, as in the first embodiment. According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**. A frequency of the carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

First Modification of Fifth Embodiment

[0160] A first modification of the fifth embodiment is described. The ultrasonic wave emitter **110** according to the fifth embodiment comprises the F-IDT **510** in which the arc-shaped interdigital electrode **512** is formed on the lithium niobate substrate **511**. In contrast, an ultrasonic wave emitter **110** according to the present embodiment comprises an IDT **520**. As shown in FIG. **26**, the IDT **520** has a configuration in which an interdigital electrode **522** that varies in width depending on the position is formed on a lithium niobate substrate **521**. The width of the interdigital electrode **522** varies depending on the position, so that the SAWs and BAWs that are generated depending on the position of the IDT **520** are different in frequency. That is, the frequency of generated acoustic waves is higher in thinner parts of the interdigital electrode **522** (lower parts in FIG. **26**), and the frequency of generated acoustic waves is lower in thicker parts of the interdigital electrode **522** (upper parts in FIG. **26**).

[0161] Such a configuration allows the output frequency band of the IDT **520** that configures the ultrasonic wave emitter **110** to be broader. Here, if there are a relatively small number of pairs, for example, about 2 to 10 pairs of engaged electrodes, the output frequency band of the IDT **520** is further broadened.

Second Modification of Fifth Embodiment

[0162] The endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment can be configured by use of the ultrasonic treatment apparatus according to the fifth embodiment or its first modification. The endoscopic ultrasonic diagnostic treatment apparatus **400** configured by use of the ultrasonic treatment apparatus according to the fifth embodiment or its first modification can provide operation and advantages similar to those in the second embodiment.

Sixth Embodiment

[0163] A sixth embodiment of the present invention is described. In an ultrasonic treatment apparatus according to the present embodiment, the F-IDT **510** described with reference to FIGS. **23**A and **238** or the IDT **520** described with reference to FIG. **26** is used as an ultrasonic wave emitter **110**, similarly to the ultrasonic wave emitter **110** according to the fifth embodiment. An ultrasonic treatment apparatus controller **200** in the ultrasonic treatment apparatus according to the present embodiment has the configuration described with reference to FIG. **16** similarly to the ultrasonic treatment apparatus controller **200** according to the third embodiment, and controls and drives the ultrasonic wave emitter **110** by a method that uses amplitude modulation.

[0164] For example, a frequency f_m of modulated waves is stored in an output information storage **215** in association with an object to be irradiated with ultrasonic waves. A frequency f_c of carrier waves is stored in the output information storage **215** in association with the distance (depth) between an ultrasonic wave emitter **110** and the object to be irradiated with ultrasonic waves. In addition, information regarding the ultrasonic waves emitted by the ultrasonic wave emitter **110**, such as the strength of the ultrasonic waves is stored in the output information storage **215**. In accordance with an input from an input unit **250**, the drive parameter setter **210** reads the information stored in the output information storage **215**. On the basis of the read information, the drive parameter setter **210** determines a signal of ultrasonic waves to be emitted from the ultrasonic wave emitter **110**, in accordance with the object to be irradiated with ultrasonic waves and the distance to the object. The drive parameter setter **210** outputs the determined ultrasonic wave signal to a drive controller **220**.

[0165] On the basis of the signal information input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for a carrier wave signal generator **242** to generate a signal, and outputs an instruction for a modulator **244** to modulate the signal. In accordance with the input from the drive controller **220**, the carrier wave signal generator **242** generates a carrier wave signal. The carrier wave signal generator **242** outputs the generated signal to the modulator **244**. The carrier wave signal is input to the modulator **244** from the carrier wave signal generator **242**. On the basis of the input from the drive controller **220**, the modulator **244** generates a modulated wave signal. The modulator **244** modulates, by the generated modulating signal, the carrier waves input from the carrier wave signal generator **242**. The modulator **244** outputs a resultant drive signal to the ultrasonic wave emitter **110**. In accordance with the drive signal input from the modulator **244**, the F-IDT **510** or the IDT **520** that configures the ultrasonic wave emitter **110** generates ultrasonic waves.

[0166] In this manner, the ultrasonic wave emitter **110** emits ultrasonic waves in accordance with, for example, the signal x(t) which is output by the modulator **244** and which is represented by, for example, Equation (2). As a result, the ultrasonic waves propagate to a target position on the carrier waves, and the ultrasonic waves having the frequency of the modulated waves are self-demodulated at the target position. That is, the ultrasonic waves having the frequency of the modulated waves are applied to the target position.

[0167] According to the ultrasonic treatment apparatus of the present embodiment having the configuration described above, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**, as in the third embodiment and the fifth embodiment. A frequency of the carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

[0168] The endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment can be configured by use of the ultrasonic treatment apparatus according to the sixth embodiment. The endoscopic ultrasonic diagnostic treatment apparatus **400** configured by use of the ultrasonic treatment apparatus according to the sixth embodiment can provide operation and advantages similar to those in the second embodiment.

Seventh Embodiment

[0169] A seventh embodiment of the present invention is described with reference to the drawings. In an ultrasonic treatment apparatus according to the present embodiment, an IDT is used as an ultrasonic wave emitter **110**, similarly to the ultrasonic wave emitter **110** according to the fifth embodiment. An ultrasonic treatment apparatus controller **200** in the ultrasonic treatment apparatus according to the present embodiment has the configuration described with reference to FIG. **18** similarly to the ultrasonic treatment apparatus controller **200** according to the fourth embodiment. The ultrasonic treatment apparatus controller **200** controls and drives the ultrasonic wave emitter **110** by a method that uses a parametric effect attributed to a difference tone.

[0170] An F-IDT **530** shown in FIG. **27** is used as the ultrasonic wave emitter **110** according to the present embodiment. A lithium niobate substrate **531** similar to the lithium niobate substrate **511** of the F-IDT **510** described in the fifth embodiment is used in the F-IDT **530**. Two arc-shaped interdigital electrodes similar to the interdigital electrode **512** of the F-IDT **510** are formed on the lithium niobate substrate **531**. That is, a first interdigital electrode **532** and a second interdigital electrode **533** are formed on the lithium niobate substrate **531** so that the central directions of sector form of these electrodes face each other. A first signal generator **232** of the ultrasonic treatment apparatus controller **200** is connected to the first interdigital electrode **532**. A second signal generator **234** is connected to the second interdigital electrode **533**. For example, the first interdigital electrode **532** functions as at least one interdigital electrode to which a first drive signal is input. For example, the second interdigital electrode **533** functions as at least another interdigital electrode to which a second drive signal is input.

[0171] The operation of the ultrasonic treatment apparatus according to the present embodiment having such a configuration is described. The ultrasonic treatment apparatus controller **200** operates as in the fourth embodiment. In response to an operator instruction input from an input unit **250**, a drive parameter setter **210** of the ultrasonic treatment apparatus controller **200** determines frequencies of carrier waves and modulated waves in accordance with a target position and an object to be irradiated with ultrasonic waves. For the determined frequencies of the carrier waves and the modulated waves, the drive parameter setter **210** determines the frequency f_1, amplitude A_1 and initial phase θ_1 of a signal generated by the first signal generator **232** and the frequency f_2, amplitude A_2 and initial phase θ_2 of the signal generated by the second signal generator **234**. Here, the drive parameter setter **210** uses frequency information stored in an output information storage **215**. The drive parameter setter **210** outputs the determined f_1, f_2, A_1, A_2, θ_1 and θ_2 to the drive controller **220**.

[0172] On the basis of the value input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for the first signal generator **232** to generate a signal having the frequency f_1, amplitude A_1 and initial phase θ_1. The drive controller **220** also outputs an instruction for the second signal generator **234** to generate a signal having the frequency f_2, amplitude A_2 and initial phase θ_2. The first signal generator **232** outputs the generated signal to the first interdigital electrode **532**. The second signal generator **234** likewise outputs the generated signal to the second interdigital electrode **533**.

[0173] As a result, the first interdigital electrode **532** and the second interdigital electrode **533** of the F-IDT **530** vibrate, and each electrode generates SAWs or BAWs. The generated SAWs or BAWs are emitted to a subject as shown in FIG. **28**. Ultrasonic waves emitted from the first interdigital electrode **532** and ultrasonic waves emitted from the second interdigital electrode **533** overlap at a focus O. Consequently, ultrasonic waves having a frequency $\Delta f=|f_1-f_2|$ which is a difference tone are generated at the focus O by the parametric effect as in the fourth embodiment.

[0174] According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**, as in the fourth embodiment and the fifth embodiment. A frequency of carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

[0175] The F-IDT **530** according to the present embodiment can be configured so that three or more interdigital electrodes **534** are formed on the lithium niobate substrate **531** as shown in FIG. **29**. Similar advantages can also be obtained by the F-IDT **530** having such a configuration.

[0176] The endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment can be configured by use of the ultrasonic treatment apparatus according to the seventh embodiment. The endoscopic ultrasonic diagnostic treatment apparatus **400** configured by use of the ultrasonic treatment apparatus according to the seventh embodiment can provide operation and advantages similar to those in the second embodiment.

Eighth Embodiment

[0177] An eighth embodiment of the present invention is described with reference to the drawings. Here, the difference between the eighth embodiment and the first embodiment is described, and the same parts as those in the first embodiment are provided with the same reference numbers and are not described. In the ultrasonic treatment apparatus according to the first embodiment, the cMUT array **320** is used as the ultrasonic wave emitter **110**. In contrast, a plano-concave piezoelectric element having a concave upper surface and a planar lower surface shown in FIG. **30** is used as an ultrasonic wave emitter **110** in the ultrasonic treatment apparatus according to the present embodiment.

[0178] In an ultrasonic element **610**, a ground electrode **612**, for example, is formed on the upper surface of a plano-concave piezoelectric element **611**, and a signal electrode **613**, for example, is formed on the lower surface of the piezoelectric element **611**. The piezoelectric element **611** gradually varies in thickness between the central portion and peripheral edge portion, and thus varies in resonance frequency from place to place. Thus, a part that mainly vibrates changes depending on the frequency of an applied voltage. For example, ultrasonic waves having a relatively high frequency are generated in the central portion where the piezoelectric element **611** is thin. Ultrasonic waves having a relatively low frequency are generated in the peripheral edge portion where the piezoelectric element **611** is thick. That is, the output frequency band of the ultrasonic element **610** is broad. The ultrasonic element **610** has, for example, an outside diameter ϕ of 12 mm, a maximum thickness of 2 mm and a concave surface center thickness of 1.2 mm.

[0179] An ultrasonic treatment apparatus controller **200** of the ultrasonic treatment apparatus according to the present embodiment is similar to the ultrasonic treatment apparatus controller **200** according to the first embodiment. The ultrasonic treatment apparatus controller **200** has the configuration described with reference to FIG. **1**. Signals generated by a first signal generator **232** and a second signal generator **234** are added together by the adder **236**, and the ultrasonic wave emitter **110** is controlled and driven.

[0180] More specifically, the ultrasonic treatment apparatus controller **200** has a drive parameter setter **210**, an output information storage **215**, a drive controller **220**, the first signal generator **232**, the second signal generator **234** and the adder **236**. In response to an operator instruction input from an input unit **250**, the drive parameter setter **210** of the ultrasonic treatment apparatus controller **200** determines frequencies of carrier waves and modulated waves in accordance with a target position and an object to be irradiated with ultrasonic waves. For the determined frequencies of the carrier waves and the modulated waves, the drive parameter setter **210** determines the frequency f_1, amplitude A_1 and initial phase θ_1 of a signal generated by the first signal generator **232** and the frequency f_2, amplitude A_2 and initial phase θ_2 of the signal generated by the second signal generator **234**. Here, the drive parameter setter **210** uses the frequency information stored in an output information storage **215**, for example, shown in FIG. **8**. The drive parameter setter **210** outputs the determined f_1, f_2, A_1, A_2, θ_1 and θ_2 to the drive controller **220**.

[0181] On the basis of the value input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for the first signal generator **232** to generate a signal having the frequency f_1, amplitude A_1 and initial phase θ_1. The drive controller **220** also outputs an instruction for the second signal generator **234** to generate a signal having the frequency f_2, amplitude A_2 and initial phase θ_2. On the basis of the instructions input from the drive controller **220** to generate ultrasonic waves, the first signal generator **232** and the second signal generator **234** respectively generate signals and output the generated signals to the adder **236**. The adder **236** adds together the inputs from the first signal generator **232** and the second signal generator **234**, and outputs a drive signal represented by, for example, Equation (1) to the ultrasonic wave emitter **110**. Consequently, this ultrasonic treatment apparatus applies ultrasonic waves having a desired frequency to the target position by the principle and operation similar to those described in the first embodiment, i.e., by using the self-demodulation effect.

[0182] According to the ultrasonic treatment apparatus of the present embodiment having the configuration described above, as in the first embodiment, ultrasonic waves of, for example, 1 to 2 MHz which is the resonance frequency of the microbubbles can be radiated even by the ultrasonic wave emitter **110** in which the frequency of output ultrasonic waves has to be high due to the size reduction of the piezoelectric element. Thus, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**. A frequency of carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

[0183] The piezoelectric element **611** of the ultrasonic element **610** has only to vary in thickness from place to place. The piezoelectric element **611** may be shaped, for example, as shown in FIGS. **31**A and **31**B. Similar advantages can be obtained in this case as well.

[0184] The endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment can be configured by use of the ultrasonic treatment apparatus according to the eighth embodiment. The endoscopic ultrasonic diagnostic treatment apparatus **400** configured by use of the ultrasonic treatment apparatus according to the eighth embodiment can provide operation and advantages similar to those in the second embodiment.

Ninth Embodiment

[0185] A ninth embodiment of the present invention is described. In an ultrasonic treatment apparatus according to the present embodiment, the ultrasonic element **610** described with reference to FIG. **30** or FIG. **31** is used as an ultrasonic wave emitter **110**, similarly to the ultrasonic wave emitter **110** according to the eighth embodiment. An ultrasonic treatment apparatus controller **200** in the ultrasonic treatment apparatus according to the present embodiment has the configuration described with reference to FIG. **16** similarly to the ultrasonic treatment apparatus controller **200** according to the third embodiment, and controls and drives the ultrasonic wave emitter **110** by a method that uses amplitude modulation.

[0186] More specifically, for example, a frequency f_m of modulated waves is stored in an output information storage **215** in association with an object to be irradiated with ultrasonic waves. A frequency f_c carrier waves is stored in the output information storage **215** in association with the distance (depth) between an ultrasonic wave emitter **110** and the object to be irradiated with ultrasonic waves. Information regarding the ultrasonic waves emitted by the ultrasonic wave emitter **110**, such as the strength of the ultrasonic waves is stored in the output information storage **215**. In accordance with an input from an input unit **250**, the drive parameter setter **210** reads the information stored in the output information storage **215**. On the basis of the read information, the drive parameter setter **210** determines a signal of ultrasonic waves to be emitted from the ultrasonic wave emitter **110**, in accordance with the object to be irradiated with ultrasonic waves and the distance to the object. The drive parameter setter **210** outputs, to a drive controller **220**, the determined information on the ultrasonic wave signal to be emitted from the ultrasonic wave emitter **110**.

[0187] On the basis of the signal information input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for a carrier wave signal generator **242** to generate a signal, and outputs an instruction for a modulator **244** to modulate the signal. In accordance with the input from the drive controller **220**, the carrier wave signal generator **242** generates a carrier wave signal. The carrier wave signal generator **242** outputs the generated signal to the modulator **244**. Carrier waves are input to the modulator **244** from the carrier wave signal generator **242**. On the basis of the input from the drive controller **220**, the modulator **244** generates a modulated wave signal. The modulator **244** modulates, by the generated modulating signal, the carrier waves input from the carrier wave signal generator **242**. The modulator **244** outputs a resultant drive signal to the ultrasonic wave emitter **110**. In accordance with the drive signal input from the modulator **244**, the ultrasonic element **610** that configures the ultrasonic wave emitter **110** generates ultrasonic waves.

[0188] In this manner, the ultrasonic wave emitter **110** emits ultrasonic waves in accordance with, for example, the signal x(t) which is output by the modulator **244** and which is represented by, for example, Equation (2). As a result, the ultrasonic waves propagate to a target position on the carrier waves, and the ultrasonic waves having the frequency of the modulated waves are self-demodulated at the target position. That is, the ultrasonic waves having the frequency of the modulated waves are applied to the target position.

[0189] According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**, as in the third embodiment and eighth embodiment. A frequency of the carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

[0190] The piezoelectric element **611** of the ultrasonic element **610** has only to vary in thickness from place to place. Therefore, as in the eighth embodiment, the piezoelectric element **611** may be shaped, for example, as shown in FIGS. **31**A and **31**B. Similar advantages can be obtained in this case as well.

[0191] The endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment can be configured by use of the ultrasonic treatment apparatus according to the ninth embodiment. The endoscopic ultrasonic diagnostic treatment apparatus **400** configured by use of the ultrasonic treatment apparatus according to the ninth embodiment can provide operation and advantages similar to those in the second embodiment.

Tenth Embodiment

[0192] A tenth embodiment of the present invention is described with reference to the drawings. In an ultrasonic treatment apparatus according to the present embodiment, a piezoelectric element that varies in thickness from place to place is used as an ultrasonic wave emitter **110**, similarly to the ultrasonic wave emitter **110** according to the eighth embodiment. An ultrasonic treatment apparatus controller **200** in the ultrasonic treatment apparatus according to the present embodiment has the configuration described with reference to FIG. **18** similarly to the ultrasonic treatment apparatus controller **200** according to the fourth embodiment, and controls and drives the ultrasonic wave emitter **110** by a method that uses a parametric effect attributed to a difference tone.

[0193] The ultrasonic wave emitter **110** according to the present embodiment includes a plano-concave piezoelectric element **621** having a concave upper surface and a planar lower surface, as shown in a sectional view in FIG. **32**A and a plane view of the lower surface in FIG. **32**B. The piezoelectric element **621** is different from the ultrasonic element **610** according to the eighth embodiment in the shape of the lower electrode. In an ultrasonic element **620** according to the present embodiment, a ground electrode **622**, for example, is formed on the upper surface of the plano-concave piezoelectric element **621**. For example, a first electrode **623** and a second electrode **624** are concentrically formed on the lower surface of the piezoelectric element **621**. A first signal generator **232** of the ultrasonic treatment apparatus controller **200** is connected to the electrode **623** of the ultrasonic element **620** having the configuration described above. A second signal generator **234** is connected to the second electrode **624**. For example, the first electrode **623** functions as at least one drive electrode to which a first drive signal is input. For example, the second electrode **624** functions as at least another drive electrode to which a second drive signal is input.

[0194] For example, when the ultrasonic element **620** is formed as shown in FIGS. **32**A and **32**B, a high-frequency signal is input to the first electrode **623**, and a low-frequency signal is input to the second electrode **624**. As a result, the central portion of the ultrasonic element **620** vibrates at a frequency input to the first electrode **623**, and the peripheral portion vibrates at a frequency input to the second electrode **624**.

[0195] The ultrasonic treatment apparatus controller **200** operates as in the fourth embodiment. That is, in response to an operator instruction input from an input unit **250**, a drive parameter setter **210** of the ultrasonic treatment apparatus controller **200** determines frequencies of carrier waves and modulated waves in accordance with a target position and an object to be irradiated with ultrasonic waves. For the determined frequencies of the carrier waves and the modulated waves, the drive parameter setter **210** determines the frequency f_1, amplitude A_1 and initial phase θ_1 of a signal generated by the first signal generator **232** and the frequency f_2, amplitude A_2 and initial phase θ_2 of a signal generated by the second signal generator **234**. Here, the drive parameter setter **210** uses frequency information stored in an output information storage **215**. The drive parameter setter **210** outputs the determined f_1, f_2, A_1, A_2, θ_1 and θ_2 to the drive controller **220**.

[0196] On the basis of the value input from the drive parameter setter **210**, the drive controller **220** outputs an instruction for the first signal generator **232** to generate a signal having the frequency f_1, amplitude A_1 and initial phase θ_1. The drive controller **220** also outputs an instruction for the second signal generator **234** to generate a signal having the frequency f_2, amplitude A_2 and initial phase θ_2. The first signal generator **232** outputs the generated signal to the first electrode **623**. The second signal generator **234** also outputs the generated signal to the second electrode **624**.

[0197] As a result, ultrasonic waves are generated from the ultrasonic element **620** by the vibration of the piezoelectric element **621**. The generated ultrasonic waves are radiated into a subject. In the subject irradiated with the ultrasonic waves, ultrasonic waves having a frequency $\Delta f=|f_1-f_2|$ which is a difference tone are generated by the parametric effect as in the fourth embodiment.

[0198] According to the ultrasonic treatment apparatus of the present embodiment, ultrasonic waves having a frequency suited for an object can be radiated regardless of the configuration of the ultrasonic wave emitter **110**, as in the fourth embodiment and eighth embodiment. A frequency of the carrier waves is properly selected in such a manner as to take the attenuation of ultrasonic waves into account in accordance with the depth of the target position to be irradiated with ultrasonic waves. This ensures that the ultrasonic treatment apparatus can apply ultrasonic waves having the frequency of the set modulated waves to various target positions. Moreover, the use and propagation of the high-frequency ultrasonic waves advantageously allow for a sharper beam pattern.

[0199] The piezoelectric element **611** of the ultrasonic element **610** has only to vary in thickness from place to place. The first electrode **623** and the second electrode **624** have only to be formed separately. Thus, for example, as shown in FIGS. **33**A and **33**B, the first electrode **623** and the second electrode **624** may be formed in a halved state. Similar advantages can be obtained in this case as well. Moreover, as in the eighth embodiment, the ultrasonic element **620** may be shaped as shown in FIGS. **34**A and **34**B. In this case as well, similar advantages can be obtained.

[0200] The endoscopic ultrasonic diagnostic treatment apparatus **400** described in the second embodiment can be configured by use of the ultrasonic treatment apparatus according to the tenth embodiment. The endoscopic ultrasonic diagnostic treatment apparatus **400** configured by use of the ultrasonic treatment apparatus according to the tenth embodiment can provide operation and advantages similar to those in the second embodiment.

[0201] Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. An ultrasonic treatment apparatus comprising:
- a sound source which emits ultrasonic waves, the ultrasonic waves being finite amplitude acoustic waves including a first signal frequency and a second signal frequency;
- a frequency setter which sets the first signal frequency and the second signal frequency in accordance with a target position of a treatment object with respect to the sound source; and
- a drive signal generator configured to generate a drive signal and to drive the sound source, the drive signal being a signal which causes the sound source to emit the ultrasonic waves.

2. The ultrasonic treatment apparatus according to claim **1**, further comprising:
- a frequency information storage to store information that associates the target position with the first signal frequency and the second signal frequency,
- wherein the frequency setter sets the first signal frequency and the second signal frequency based on the information stored in the frequency information storage.

3. The ultrasonic treatment apparatus according to claim **1**, further comprising a position information input unit to input the target position.

4. The ultrasonic treatment apparatus according to claim **1**, wherein the drive signal generator comprises
- a signal generator which generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and
- an adder which adds the first drive signal and the second drive signal together to generate an additional drive signal; and
- the sound source is driven by the additional drive signal.

5. The ultrasonic treatment apparatus according to claim **1**, wherein the drive signal generator generates the drive signal by amplitude modulation.

6. The ultrasonic treatment apparatus according to claim **1**, wherein the sound source comprises ultrasonic wave emitters,
- the drive signal generator generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and
- at least one of the ultrasonic wave emitters is driven by the first drive signal, and at least one of the ultrasonic wave emitters is driven by the second drive signal.

7. The ultrasonic treatment apparatus according to claim **1**, wherein the sound source comprises a capacitive transducer.

8. The ultrasonic treatment apparatus according to claim **7**, wherein the capacitive transducer includes
- a vibrating film, and
- a head which is formed on the vibrating film and which brings vibrating directions into one direction.

9. The ultrasonic treatment apparatus according to claim **7**, wherein the drive signal generator comprises
- a signal generator which generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and
- an adder which adds the first drive signal and the second drive signal together to generate an additional drive signal; and
- the sound source is driven by the additional drive signal.

10. The ultrasonic treatment apparatus according to claim **7**, wherein the drive signal generator generates the drive signal by amplitude modulation.

11. The ultrasonic treatment apparatus according to claim **1**, wherein the sound source comprises capacitive transducers, and
- each of the capacitive transducers includes
- a vibrating film, and

a head which is formed on the vibrating film and which brings vibrating directions into one direction, the head being sloped.

12. The ultrasonic treatment apparatus according to claim **11**, wherein the drive signal generator selects the capacitive transducer to be driven by the drive signal among the capacitive transducers based on a slope of the head in accordance with the target position.

13. The ultrasonic treatment apparatus according to claim **1**, wherein the sound source comprises capacitive transducers,

the drive signal generator generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and

at least one of the capacitive transducers is driven by the first drive signal, and at least one of the capacitive transducers is driven by the second drive signal.

14. The ultrasonic treatment apparatus according to claim **1**, wherein the sound source comprises an interdigital electrode transducer including a piezoelectric substrate and an interdigital electrode formed on the piezoelectric substrate.

15. The ultrasonic treatment apparatus according to claim **14**, wherein the interdigital electrode is arc-shaped, and

the ultrasonic waves generated by the interdigital electrode transducer propagates in a direction of a center of the arc.

16. The ultrasonic treatment apparatus according to claim **14**, wherein the interdigital electrode is shaped to continuously vary in width in a longitudinal direction of the interdigital electrode.

17. The ultrasonic treatment apparatus according to claim **14**, wherein the piezoelectric substrate comprises Y-cut X-propagation lithium niobate.

18. The ultrasonic treatment apparatus according to claim **14**, wherein the finite amplitude acoustic waves have a frequency included in a frequency band of surface acoustic waves or bulk waves generated by the interdigital electrode transducer.

19. The ultrasonic treatment apparatus according to claim **14**, wherein the interdigital electrode transducer comprises interdigital electrodes, the interdigital electrodes being arranged so that traveling directions of the ultrasonic waves generated from the respective interdigital electrodes intersect with one another.

20. The ultrasonic treatment apparatus according to claim **19**, wherein the drive signal generator generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and

the first drive signal is input to at least one of the interdigital electrodes, and the second drive signal is input to at least one of the interdigital electrodes.

21. The ultrasonic treatment apparatus according to claim **14**, wherein the drive signal generator comprises

a signal generator which generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and

an adder which adds the first drive signal and the second drive signal together to generate an additional drive signal; and

the sound source is driven by the additional drive signal.

22. The ultrasonic treatment apparatus according to claim **14**, wherein the drive signal generator generates the drive signal by amplitude modulation.

23. The ultrasonic treatment apparatus according to claim **1**, wherein the sound source comprises a piezoelectric element varying in thickness from place to place.

24. The ultrasonic treatment apparatus according to claim **23**, wherein the piezoelectric element is a plano-concave element.

25. The ultrasonic treatment apparatus according to claim **23**, wherein the piezoelectric element comprises

a common electrode formed on a first main surface, and

drive electrodes formed on a second main surface opposite to the first main surface on which the common electrode is formed, the drive electrodes being supplied with the drive signal.

26. The ultrasonic treatment apparatus according to claim **25**, wherein the drive electrodes are concentrically arranged.

27. The ultrasonic treatment apparatus according to claim **25**, wherein the piezoelectric element comprises two drive electrodes formed in the second main surface opposite to the first main surface on which the common electrode is formed, the drive electrodes being supplied with the drive signal.

28. The ultrasonic treatment apparatus according to claim **25**, wherein the drive signal generator generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and

the first drive signal is input to at least one of the drive electrodes, and the second drive signal is input to at least one of the drive electrodes.

29. The ultrasonic treatment apparatus according to claim **23**, wherein the drive signal generator comprises

a signal generator which generates a first drive signal having the first signal frequency and a second drive signal having the second signal frequency, and

an adder which adds the first drive signal and the second drive signal together to generate an additional drive signal; and

the sound source is driven by the additional drive signal.

30. The ultrasonic treatment apparatus according to claim **23**, wherein the drive signal generator generates the drive signal by amplitude modulation.

31. The ultrasonic treatment apparatus according to claim **1**, further comprising an image acquisition signal setter which sets an image acquisition emission ultrasonic wave signal for ultrasonic image acquisition by emitting imaging ultrasonic waves which are finite amplitude acoustic waves having the frequency of the image acquisition emission ultrasonic wave signal and by receiving reflected waves,

wherein in the ultrasonic image acquisition, the drive signal generator generates a drive signal causing the sound source to emit the imaging ultrasonic waves, instead of the drive signal causing the sound source to emit the ultrasonic waves which are the finite amplitude acoustic waves including the first signal frequency and the second signal frequency.

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摘要(译)

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