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**Oshiki et al.**

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(54) **ULTRASONIC DIAGNOSTIC APPARATUS AND METHOD THEREOF**

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(51) **Int. Cl.**

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| ***A61B 8/00*** | (2006.01) |
| ***G01N 29/24*** | (2006.01) |
| ***G01N 29/26*** | (2006.01) |
| ***G01S 7/52*** | (2006.01) |
| ***G10K 11/34*** | (2006.01) |
| ***G01S 15/89*** | (2006.01) |

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CPC ***A61B 8/00*** (2013.01); ***G01N 29/24*** (2013.01); ***G01N 29/262*** (2013.01); ***G01S 7/52019*** (2013.01); ***G01S 7/5208*** (2013.01); ***G10K 11/346*** (2013.01); ***G01S 15/8915*** (2013.01)

(58) **Field of Classification Search**
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USPC .................................. 367/127; 600/300, 437
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,301,167 A * 4/1994 Proakis et al. ................ 367/134
5,590,658 A * 1/1997 Chiang et al. ................ 600/447

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2005-152450 6/2005
JP 2007-325937 12/2007

(Continued)

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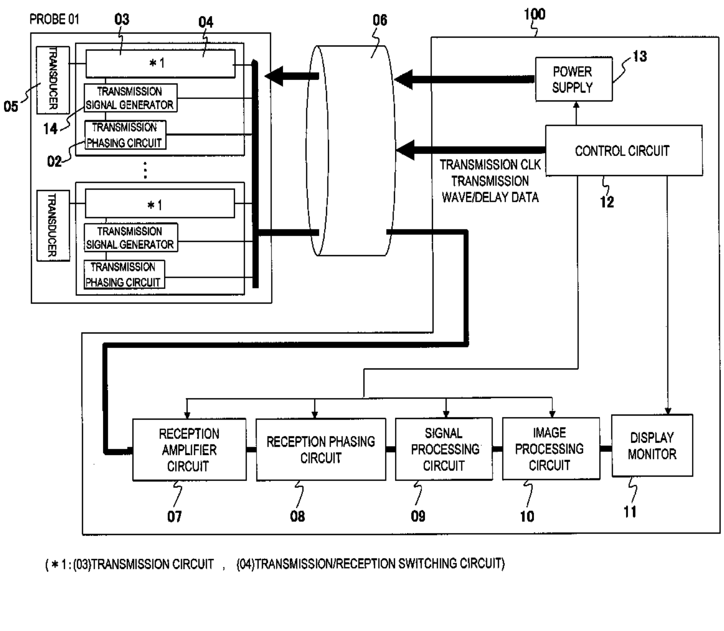
(74) *Attorney, Agent, or Firm* — Brundidge & Stanger, P.C.

(57) **ABSTRACT**

An ultrasonic diagnostic apparatus characterized by comprising, a probe which has a transducer and which transmits and receives ultrasonic waves, an ultrasonic diagnostic apparatus main body; and a cable through which signals are transmitted and received between the ultrasonic diagnostic apparatus main body and the probe, wherein the probe includes a transmission signal generator that generates an ultrasonic transmission signal, a transmission circuit that amplifies the generated transmission signal, and a transmission phasing circuit that adjusts the timing of the transmission signal.

**13 Claims, 11 Drawing Sheets**




(*1: (03)TRANSMISSION CIRCUIT , (04)TRANSMISSION/RECEPTION SWITCHING CIRCUIT)

(56) **References Cited**

U.S. PATENT DOCUMENTS

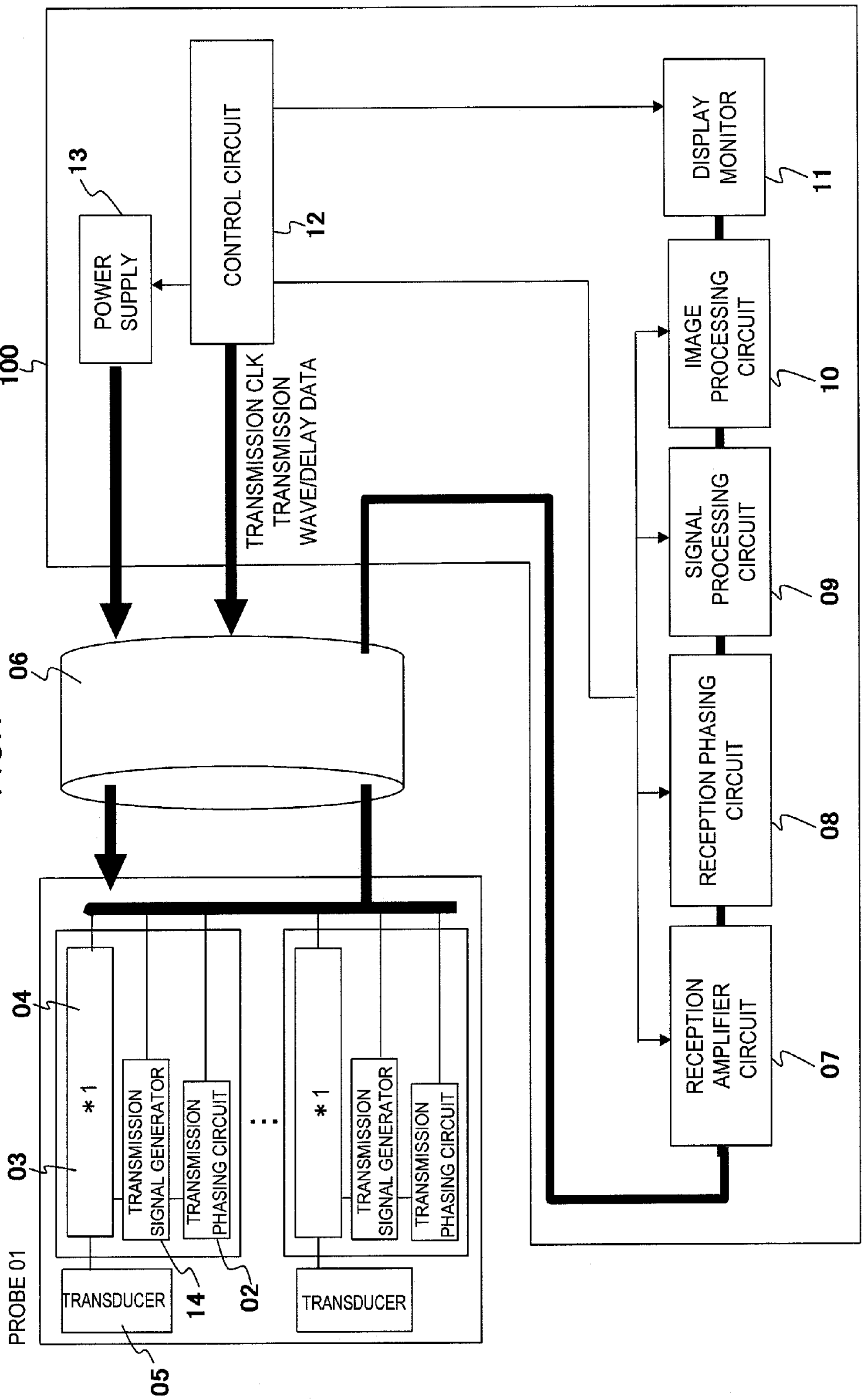
| | | | | |
|---|---|---|---|---|
| 6,072,427 | A * | 6/2000 | McEwan | 342/175 |
| 2005/0148872 | A1* | 7/2005 | Richard | 600/443 |
| 2005/0148874 | A1* | 7/2005 | Brock-Fisher et al. | 600/447 |
| 2007/0083119 | A1* | 4/2007 | Adachi et al. | 600/437 |
| 2007/0232893 | A1* | 10/2007 | Tanioka | 600/407 |
| 2009/0005683 | A1* | 1/2009 | Hashimoto et al. | 600/443 |

FOREIGN PATENT DOCUMENTS

| | | |
|---|---|---|
| JP | 2008-259891 | 10/2008 |
| WO | 2005/120359 | 12/2005 |

* cited by examiner

FIG.1




(*1:(03)TRANSMISSION CIRCUIT , (04)TRANSMISSION/RECEPTION SWITCHING CIRCUIT)

FIG.2

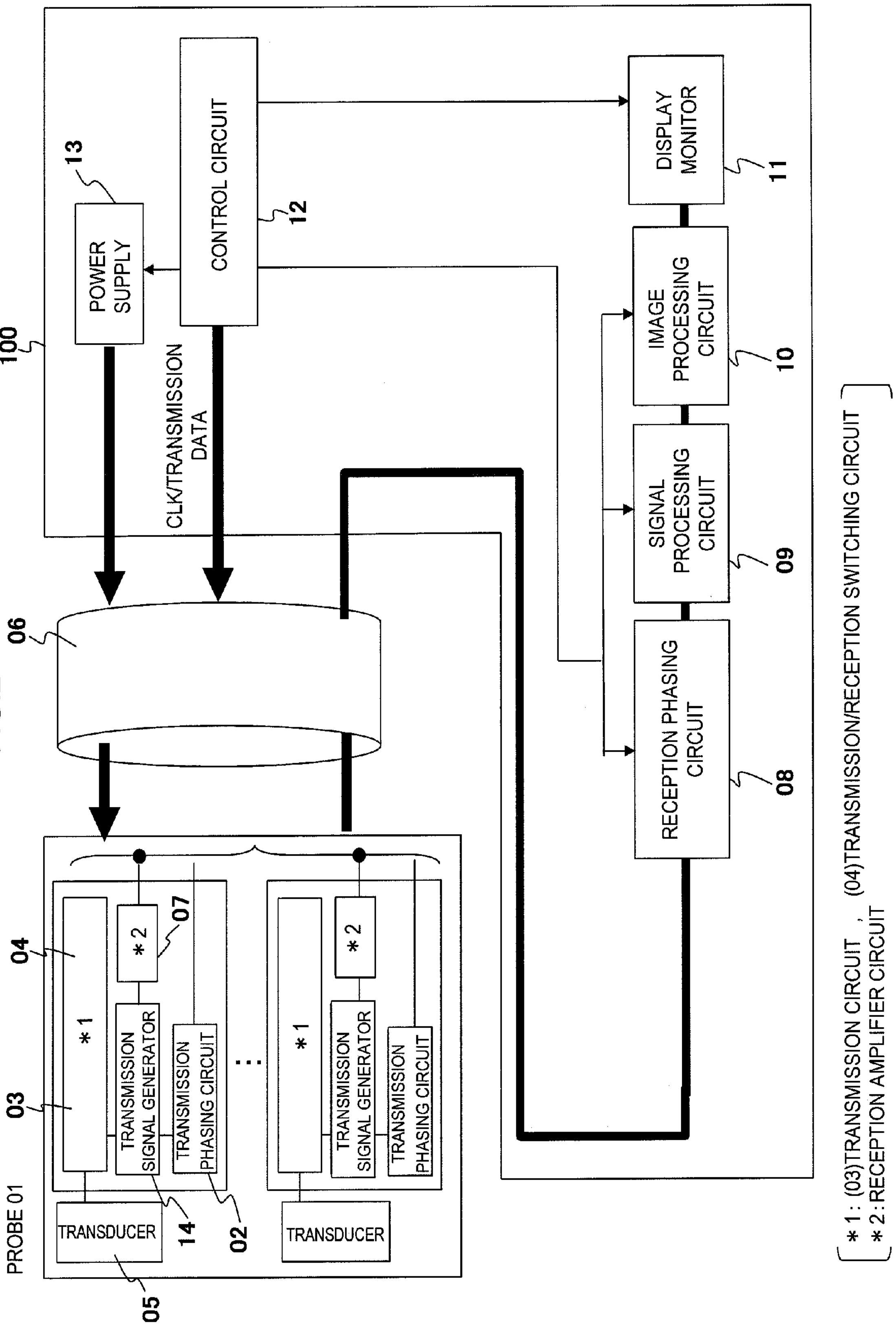
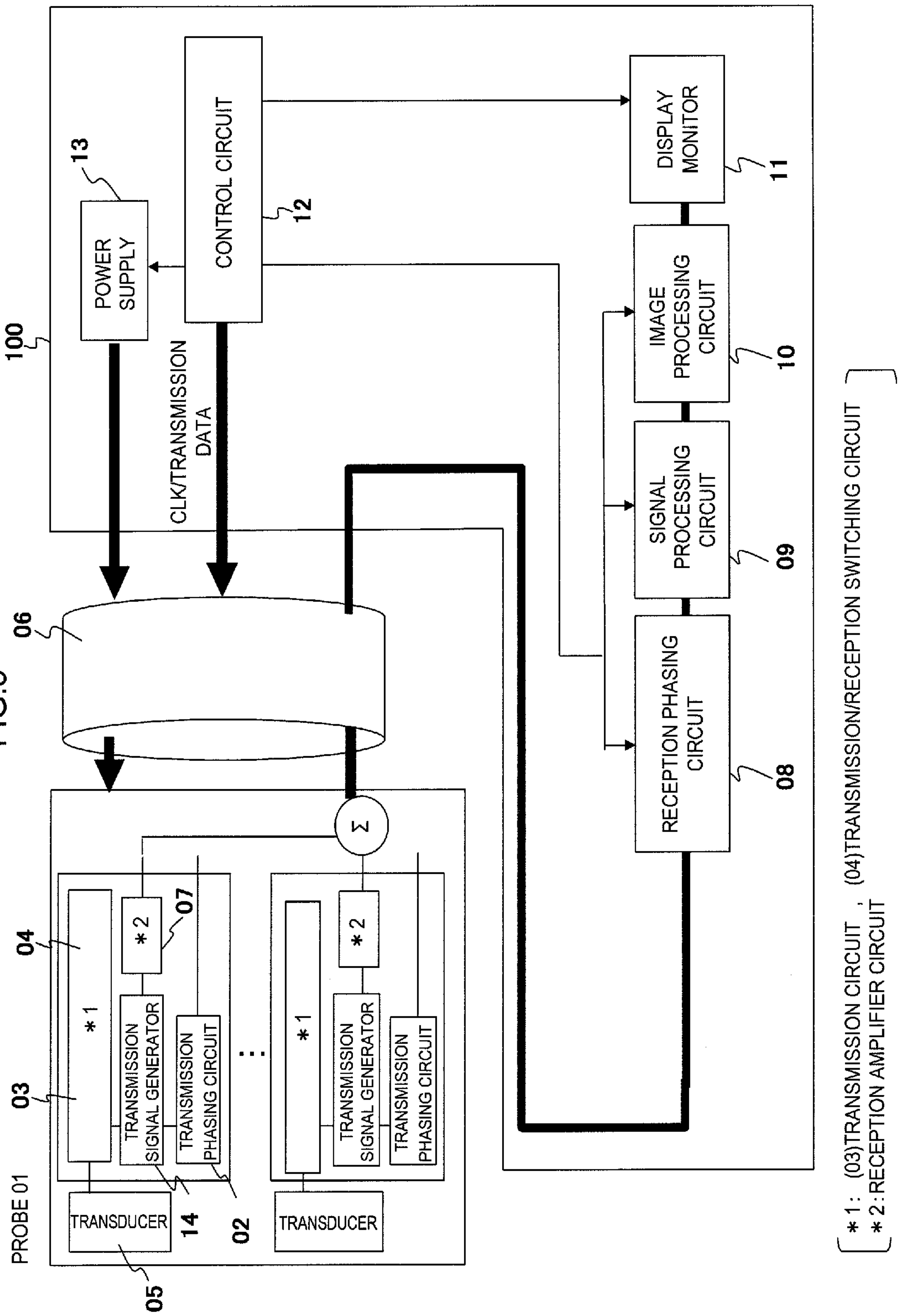

100
POWER SUPPLY
13
CONTROL CIRCUIT
12
DISPLAY MONITOR
11
IMAGE PROCESSING CIRCUIT
10
SIGNAL PROCESSING CIRCUIT
09
RECEPTION PHASING CIRCUIT
08
CLK/TRANSMISSION DATA
06
PROBE 01
04
03
*1
*2
07
TRANSMISSION SIGNAL GENERATOR
TRANSMISSION PHASING CIRCUIT
TRANSDUCER
14
02
05
*1 : (03)TRANSMISSION CIRCUIT , (04)TRANSMISSION/RECEPTION SWITCHING CIRCUIT
*2 : RECEPTION AMPLIFIER CIRCUIT

FIG.3



100
POWER SUPPLY
13
CONTROL CIRCUIT
12
DISPLAY MONITOR
11
CLK/TRANSMISSION DATA
IMAGE PROCESSING CIRCUIT
10
SIGNAL PROCESSING CIRCUIT
09
RECEPTION PHASING CIRCUIT
08
06
Σ
PROBE 01
04
03
*1
*2
07
TRANSMISSION SIGNAL GENERATOR
TRANSMISSION PHASING CIRCUIT
14
02
TRANSDUCER
05
*1: (03)TRANSMISSION CIRCUIT , (04)TRANSMISSION/RECEPTION SWITCHING CIRCUIT
*2: RECEPTION AMPLIFIER CIRCUIT

FIG.4

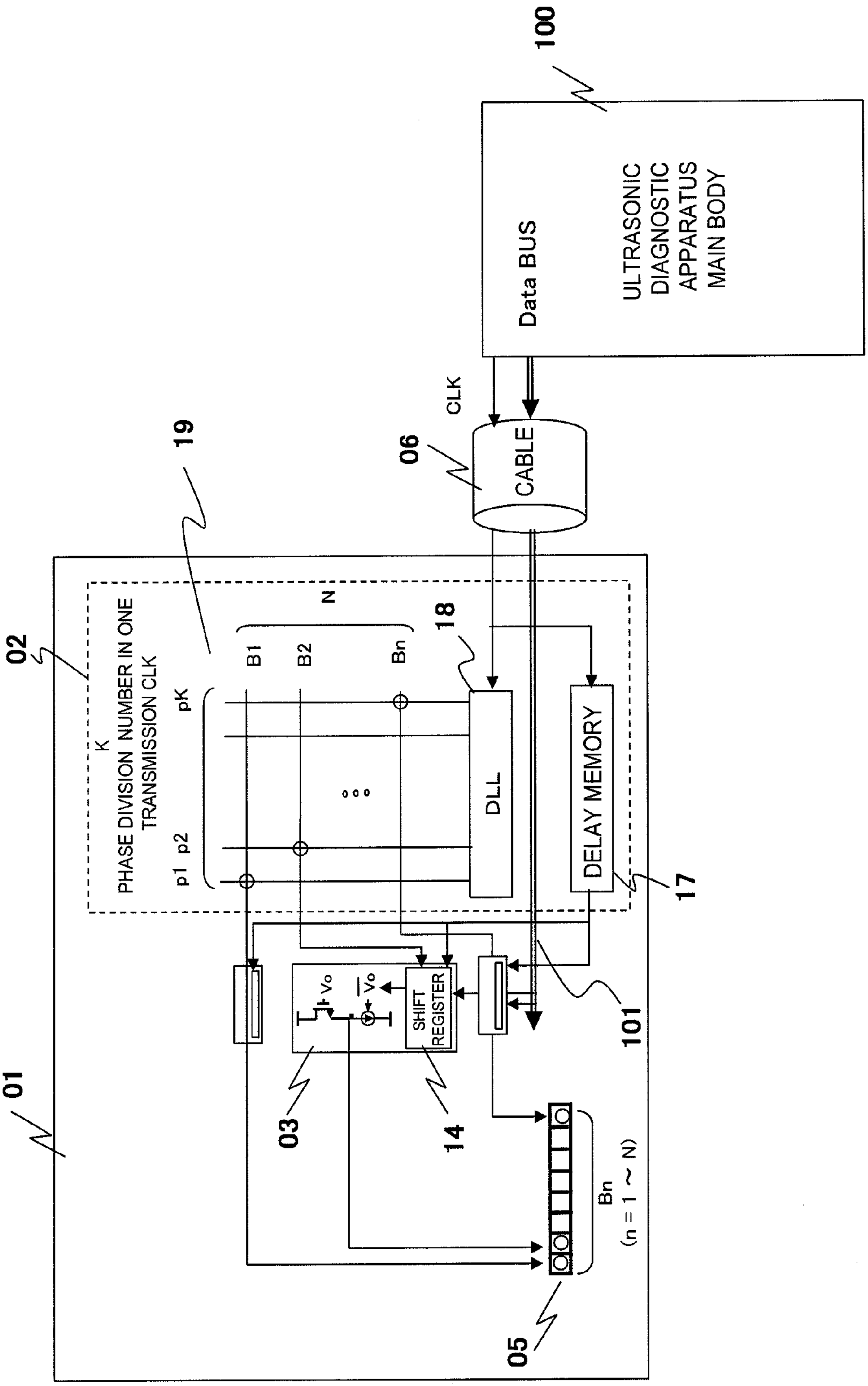

100
ULTRASONIC DIAGNOSTIC APPARATUS MAIN BODY
Data BUS
CLK
06
CABLE
19
02
PHASE DIVISION NUMBER IN ONE TRANSMISSION CLK
K
p1 p2
pK
B1
B2
Bn
N
18
DLL
DELAY MEMORY
17
101
Vo
SHIFT REGISTER
01
03
14
05
Bn
(n = 1 ~ N)

FIG.5

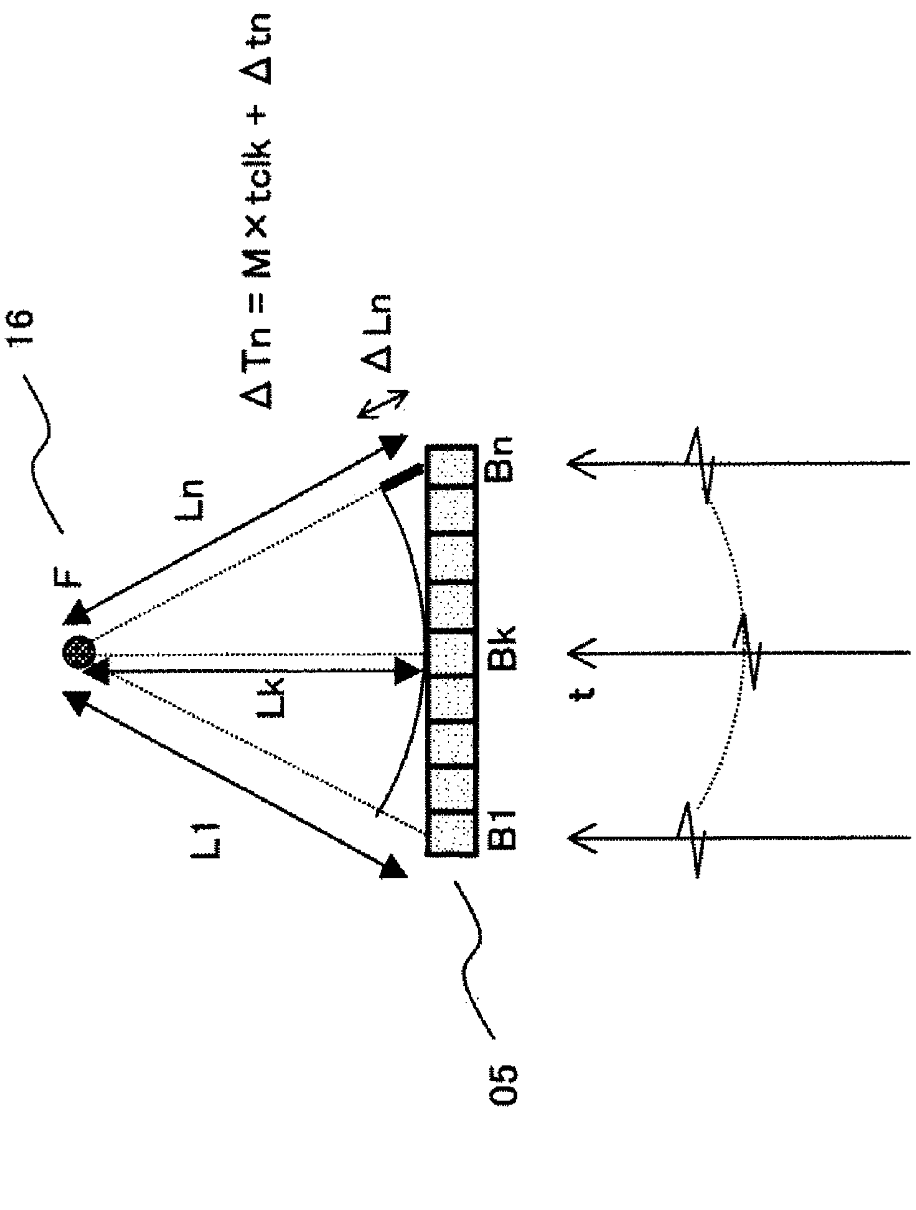


FIG.6

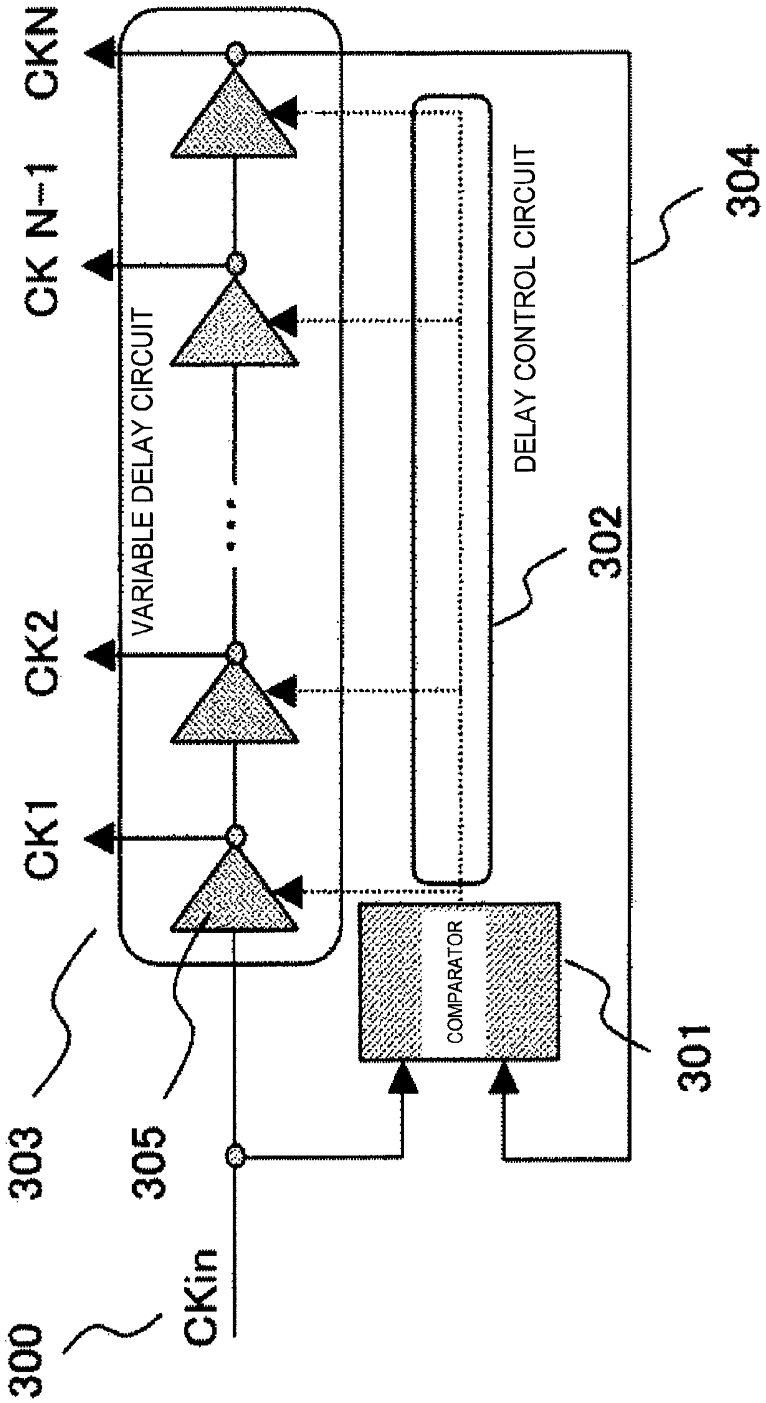

CKN
CK N−1
CK2
CK1
VARIABLE DELAY CIRCUIT
DELAY CONTROL CIRCUIT
COMPARATOR
CKin
300
301
302
303
304
305

FIG.7

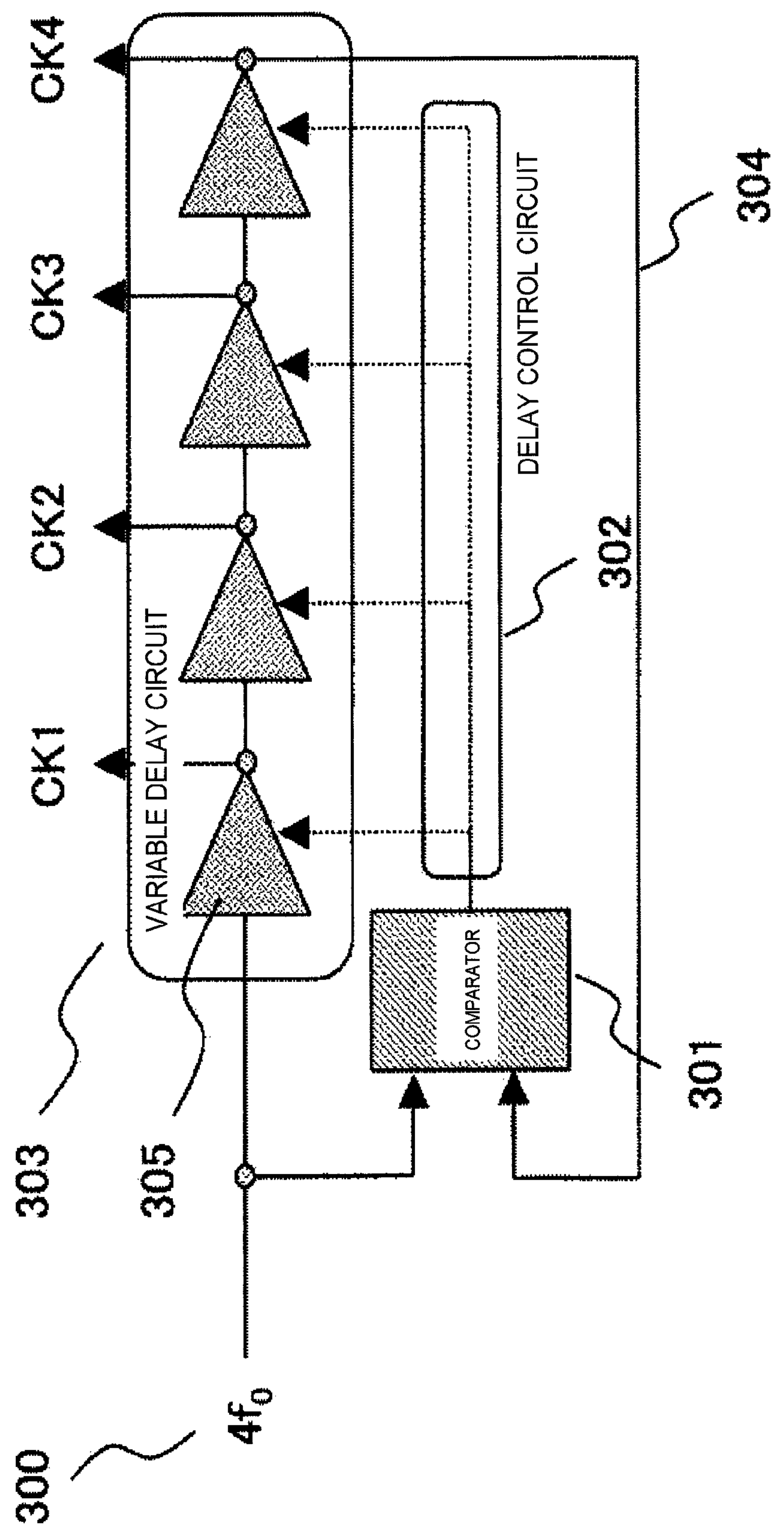

CK1
CK2
CK3
CK4
VARIABLE DELAY CIRCUIT
DELAY CONTROL CIRCUIT
COMPARATOR
300
301
302
303
304
305
$4f_0$

FIG.8

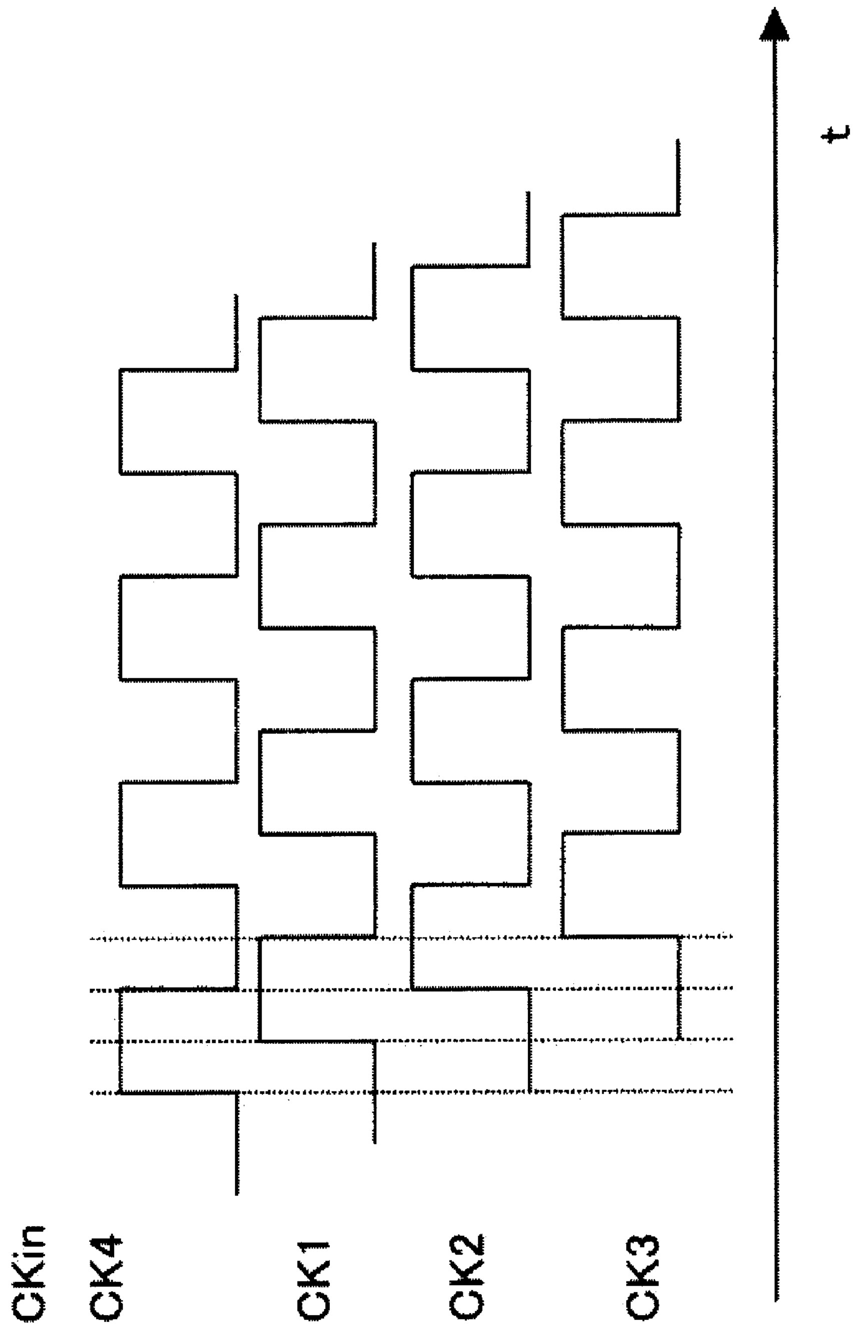


FIG.9

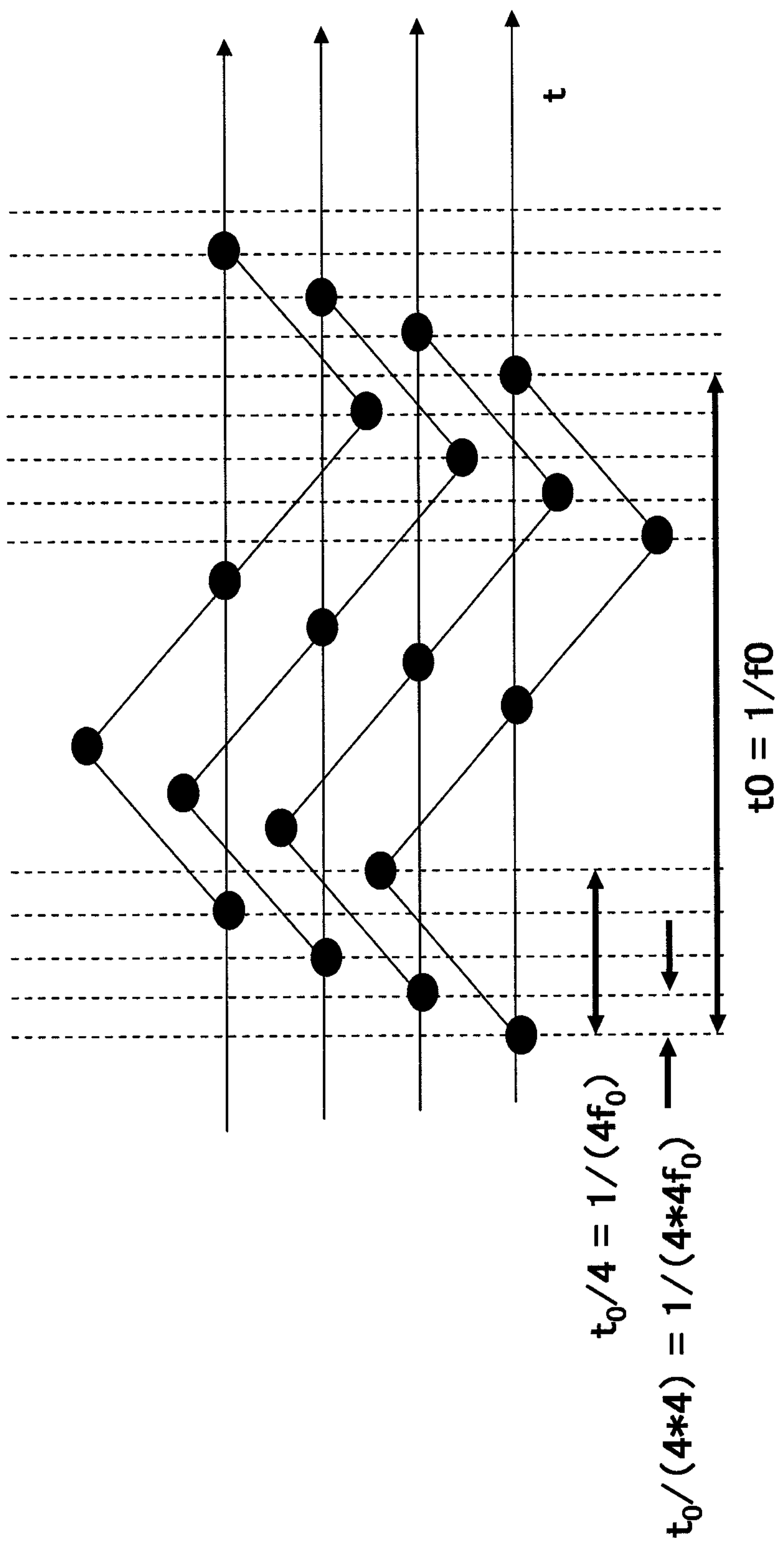
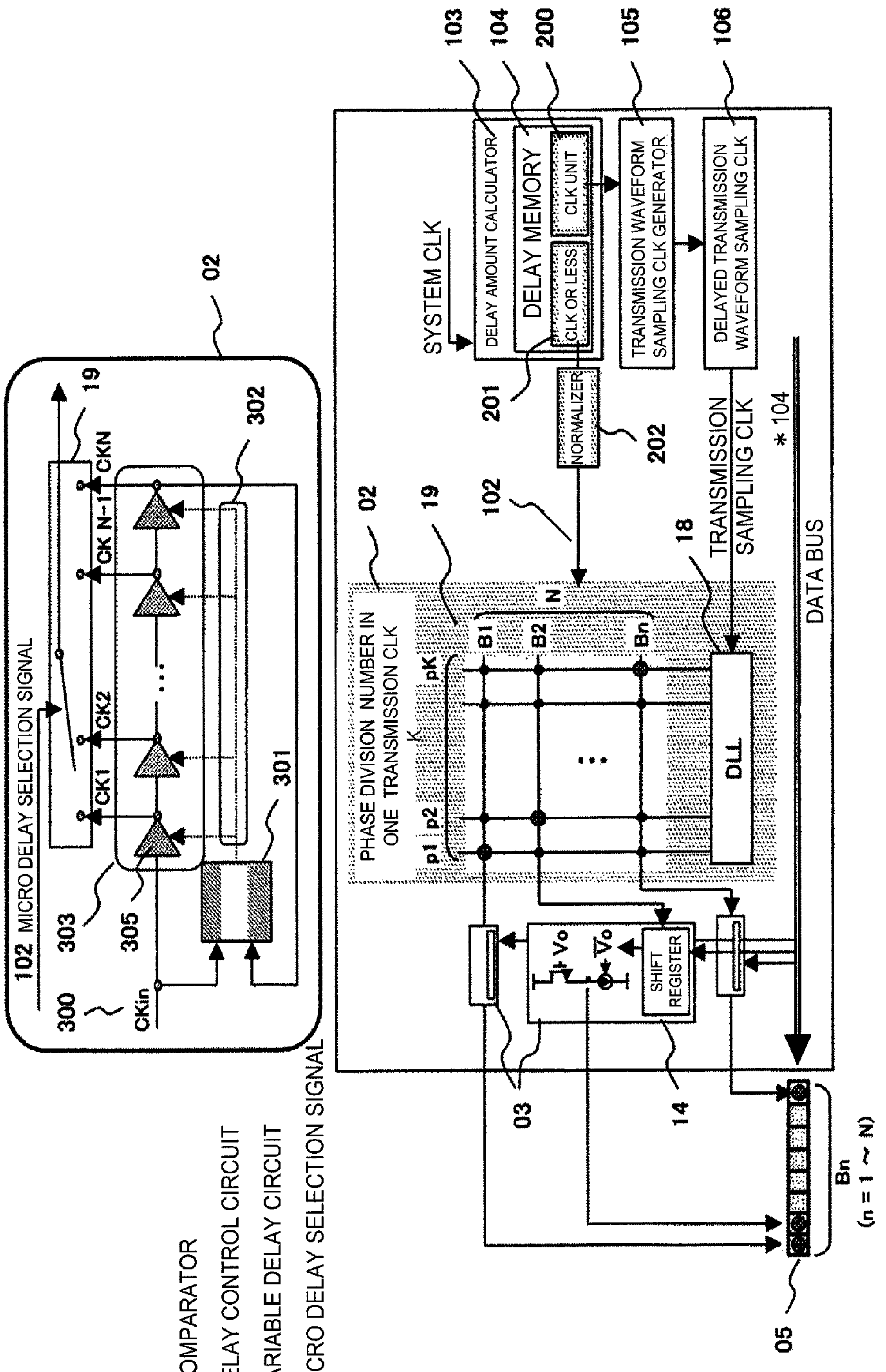
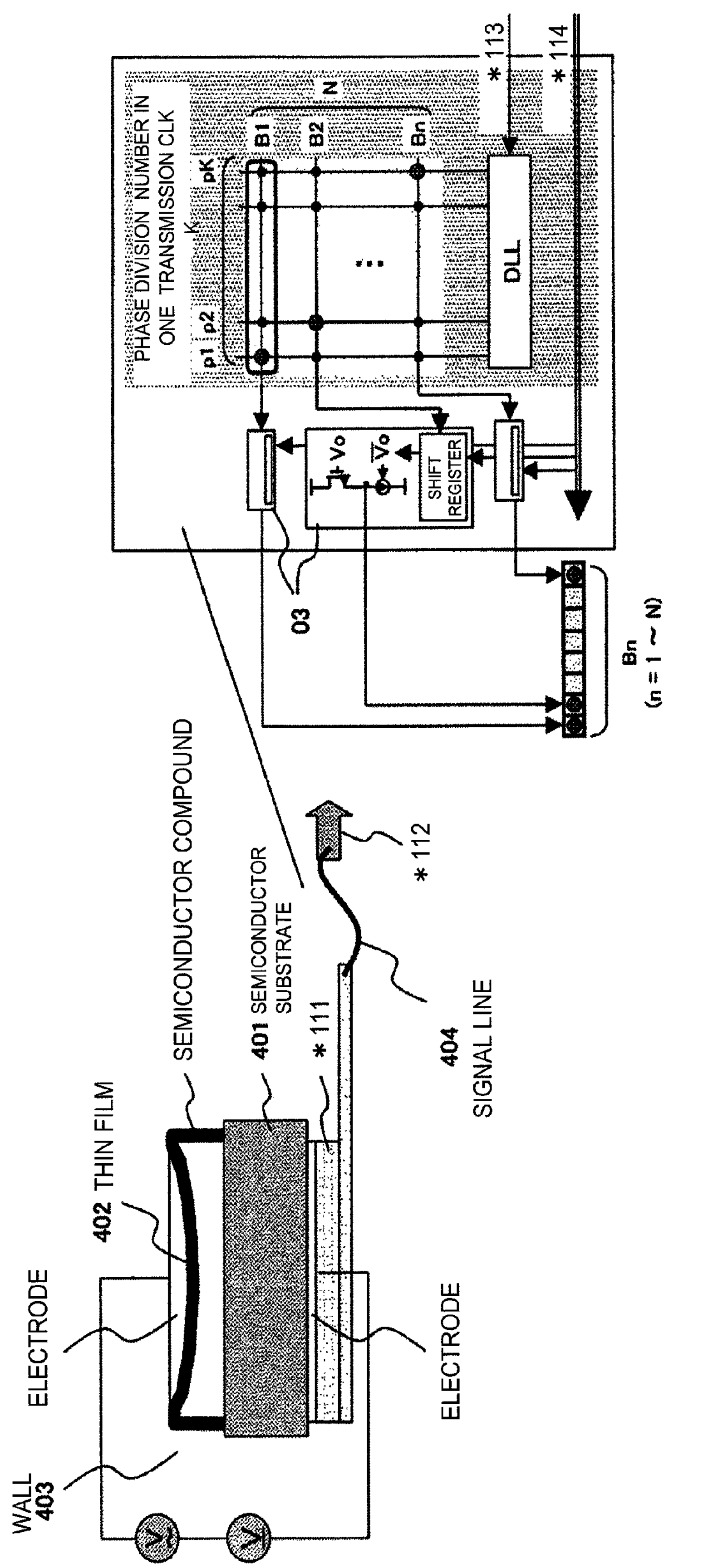


FIG.10




301: COMPARATOR
302: DELAY CONTROL CIRCUIT
303: VARIABLE DELAY CIRCUIT
102: MICRO DELAY SELECTION SIGNAL

FIG.11




＊111: IC TRANSMISSION/RECEPTION CIRCUIT
＊112: TO ULTRASONIC DIAGNOSTIC APPARATUS MAIN BODY
＊113: TRANSMISSION SAMPLING CLK
＊114: TRANSMISSION WAVEFORM DATA

# ULTRASONIC DIAGNOSTIC APPARATUS AND METHOD THEREOF

## TECHNICAL FIELD

The invention relates to an ultrasonic diagnostic apparatus. More particularly, the invention relates to an ultrasonic diagnostic apparatus in which a probe that transmits and receives ultrasonic waves includes a transmission signal generator including a transmission circuit that drives a transducer, a transmission waveform storage memory, and the like, and a transmission phasing function is incorporated into the probe, so that an analog signal line through which a high-voltage transmission signal is transmitted from the device main body to the probe is not necessary.

## BACKGROUND ART

An ultrasonic diagnostic apparatus is a device that applies a voltage to a transducer mainly formed of a piezoelectric material, transmits ultrasonic waves generated by the transducer to a subject, and extracts various kinds of information from the reflection waves to thereby obtain internal information of the subject.

In the related art, a number of transmission circuits that apply a voltage to transducers are formed in a device main body, and the number corresponds to the number of phasing bores which is generally several tens of channels. If the number of transducers in a probe is greater than the number of phasing bores, one channel of the transmission circuits and a plurality of transducers are used by being switched by a switch that is provided in the device.

Moreover, in recent years, a 2-dimensional array ultrasonic probe in which transducers are arranged 2-dimensionally has been developed. If the transducers are arranged in a 32-by-32 arrangement, the total number of transducers becomes 1024. Thus, when all transducers are driven, a matrix-type switch or the like which requires complex control needs to be provided between the driving transducers and the transmission circuits of several tens of channels provided in the device main body.

However, such a configuration is not practical because the input capacitance or the like of the switch causes a problem. Thus, it is necessary to take measures such as limiting the transducers driven by the respective transmission circuits to a certain number of effective transducers. In all cases, it is necessary to control the matrix-type switch which requires complex control.

As described above, in the related art, in order to drive many transducers, it is necessary to transmit a number of analog transmission signals, which correspond to the number of transmission circuits and which have sufficient amplitude necessary for obtaining a diagnostic image, from an ultrasonic diagnostic apparatus main body to the probe through a cable.

Patent Literature 1 discloses an invention relating to a transmission circuit which can be incorporated into a probe.

In the transmission circuit disclosed in Patent Literature 1, the transmission circuit is configured as a switch to decrease the size thereof so as to be incorporated into a probe. By doing so, it may be not necessary to transmit an analog signal having large amplitude from the ultrasonic diagnostic apparatus main body.

However, a number of signal lines for transmitting transmission input signals corresponding to the number of transmission circuits need to be included in the cable.

Moreover, it is still necessary to use a changeover switch in order to absorb the difference in number between the transmission circuits and the transducers.

Furthermore, Patent Literature 1 does not have any description a method of controlling the internal transmission circuits from the side of the main body of the ultrasonic diagnostic apparatus, the relation of the numbers of transmission circuits and transducers, and transmission phasing.

In addition, Patent Literature 2 discloses an invention relating to control of delay in transmission phasing. Specifically, Patent Literature 2 discloses transmission means having means for controlling the transmission timing of an ultrasonic wave signal with a precision that is ¼ of a sampling clock cycle used for actual transmission by using 4-phase clock signals which are delayed in time with respect to a principal clock.

However, the proposal cannot realize a delay corresponding to finer precision since the delay precision is fixed to ¼ of the sampling clock cycle.

## CITATION LIST

### Patent Literature

PTL 1: U.S. Pat. No. 7,022,074

PTL 2: JP-A-2006-288851

## SUMMARY OF THE INVENTION

### Technical Problem

As described above, although an invention relating to incorporation of transmission circuits into a probe is known in the related art, the invention does not disclose the specific control method and a technique of incorporating a transmission phasing function into the probe.

Moreover, in the invention known in the related art, the number of signal lines through which signals are transmitted from the diagnostic device main body to the probe increases as the number of incorporated transmission circuits increases.

Furthermore, although there are many transducers, the transducers capable of actually transmitting ultrasonic wave signals are limited to the number of transmission circuits smaller than the number of transducers.

An object of the invention is to provide an ultrasonic diagnostic apparatus in which circuits such as a transmission signal generator and a transmission circuit can be incorporated into a probe, thus making it unnecessary to transmit a high-voltage signal from an ultrasonic diagnostic apparatus main body and further decreasing the number of transmission cables to less than that required in the related art.

### Solution to Problem

The invention provides an ultrasonic diagnostic apparatus including a probe which has a transducer and which transmits and receives ultrasonic waves; an ultrasonic diagnostic apparatus main body; and a cable through which signals are transmitted and received between the ultrasonic diagnostic apparatus main body and the probe, wherein the probe includes a transmission signal generator that generates an ultrasonic transmission signal; a transmission circuit that amplifies the generated transmission signal; and a transmission phasing circuit that adjusts the timing of the transmission signal.

The transmission signal generator is configured by a memory, for example, a shift register, that stores transmission signal waveforms. The transmission waveforms are written in advance in the shift register and may be transmitted from the ultrasonic diagnostic apparatus main body or the like to the shift register in the probe whenever transmission is performed. In order to forma beam at a desired focus point, it is necessary to apply a delay time to each transducer that transmits ultrasonic waves. A clock signal having a phase condition corresponding to a unique delay time is applied to each transducer, and a transmission waveform is read from the shift register and transmitted to the transmission circuit. The transmission waveform is amplified to an amplitude level sufficient for driving the transducer and is then applied to the transducer, whereby an ultrasonic wave signal is obtained.

The unique clock timing having phasing information determined for each driving transducer is set in advance or is determined based on focus data which is calculated internally. The delay in units of a transmission clock can be realized by delaying the readout timing of the shift register, and the delay equal to or smaller than the transmission clock unit is generated by a DLL (Delay Locked Loop) circuit, for example.

Therefore, the signals which need to be transmitted from the device main body to the probe include only a power supply which drives the transmission circuit, a transmission clock, and waveform data. Accordingly, transmission amplification having the transmission phasing function can be realized within the probe.

Moreover, since the delay signal is created by the DLL circuit, it is not necessary to use a high-speed clock and it is possible to realize a transmission phasing circuit at a low cost and with a simple circuit configuration.

Moreover, in the ultrasonic diagnostic apparatus of the invention, the probe may have a plurality of transducers, and the transmission signal generator, the transmission circuit, and the transmission phasing circuit may be independently provided to each transducer.

In the ultrasonic diagnostic apparatus, since it is possible to apply an independent phasing condition to each transducer, it is possible to form an acoustic field using all transducers of the probe unlike the related art where the number of transducers is limited by the number of transmission channels of the device main body side.

As a result, in the invention, it is not necessary to use a changeover switch which is required in the ultrasonic diagnostic apparatus of the related art in order to absorb the difference in total numbers of the transmission circuits and the transducers which are more than the number of transmission circuits. Therefore, it is possible to eliminate signal attenuation due to the resistance component of switches, and a change in the transmission/reception signal waveform due to phase rotation or the like caused by the capacitance component.

Moreover, in the ultrasonic diagnostic apparatus of the invention, no analog transmission cable is provided between the ultrasonic diagnostic apparatus main body and the probe.

Since the signals input to the probe having the transmission circuit of the invention include only the power supply, the transmission clock, and waveform data as necessary, the high-voltage analog signal lines which are provided for transmission channels between the device main body and the transducers in the related art are not needed. Moreover, since digital communication is possible, it is possible to decrease the number of transmission cables.

Furthermore, since transmission of a high-voltage analog signal is not necessary, data can be transmitted wirelessly from the device main body to the probe of the present application.

## Advantageous Effects of the Invention

As described above, according to the invention, a transmission phasing circuit, a transmission signal generator, and a transmission circuit can be incorporated into a probe of an ultrasonic diagnostic apparatus. In this way, it is not necessary to transmit a high-voltage signal from the main body of the ultrasonic diagnostic apparatus.



Moreover, since the device main body only needs to transmit a principal clock, a power supply, and a digital transmission signal through a data bus, it is not necessary to transmit an analog transmission signal. Thus, it is possible to decrease the number of transmission cables corresponding to the number of transmission circuits required in the related art.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an ultrasonic diagnostic apparatus according to a first embodiment of the invention.

FIG. **2** is a block diagram of an ultrasonic diagnostic apparatus according to a second embodiment of the invention.

FIG. **3** is a block diagram of an ultrasonic diagnostic apparatus according to a third embodiment of the invention.

FIG. **4** is a block diagram showing a circuit incorporated in a probe of the ultrasonic diagnostic apparatus according to the invention.

FIG. **5** is a diagram showing the principle of rectifying the transmission wave phase in the ultrasonic diagnostic apparatus.

FIG. **6** is a diagram showing a micro delay circuit using a DLL circuit.

FIG. **7** is a diagram showing a micro delay circuit using a DLL circuit.

FIG. **8** is a diagram showing the output of the DLL circuit shown in FIG. **7**.

FIG. **9** is a diagram showing a delayed transmission signal output by the DLL circuit shown in FIG. **7**.

FIG. **10** is a block diagram showing an embodiment of creating a micro delay selection signal and a transmission sampling CLK.

FIG. **11** is a block diagram of an ultrasonic diagnostic apparatus according to a fourth embodiment of the invention.

## DESCRIPTION OF EMBODIMENTS

Hereinafter, preferred embodiments of the invention will be described with reference to the drawings. However, the invention is not limited to the embodiments.

### First Embodiment

FIG. **1** shows an ultrasonic diagnostic apparatus according to a first embodiment of the invention.

The circuit is configured to include a probe **01**, a cable **06**, and an ultrasonic diagnostic apparatus main body **100**. The probe **01** includes a transducer **05**, a transmission phasing circuit **02**, a transmission circuit **03**, a transmission signal generator **14**, and a transmission/reception switching circuit **04**. Moreover, a reception amplifier circuit **07**, a reception phasing circuit **08**, a signal processing circuit **09**, an image processing circuit **10**, and a display monitor **11** are provided in the main body **100**.

The main body **100** also includes a control circuit **12** and a power supply **13**.

The transducer **05** is formed so as to have a function of converting a transmission signal input from the transmission circuit **03** in the form of pulse waves or continuous waves into ultrasonic waves and transmitting the ultrasonic waves to a subject and a function of receiving ultrasonic waves reflected from the inner part of the subject and converting and outputting the ultrasonic waves into electrical signals.

The transmission phasing circuit **02** is configured to adjust the timing of applying a voltage to each driving transducer so as to be different for each of the transducers when forming transmission beams on a subject. In general, the timing is controlled so that a voltage is applied to a transducer located farther from a focusing position at an earlier time than other driving transducers.

The transmission circuit **03** is configured to amplify a transmission signal waveform formed by the transmission signal generator **14** to a magnitude sufficient for driving the transducer **05** and generating an ultrasonic wave signal and to output the amplified transmission signal waveform.

The transmission signal generator **14** is configured to determine the shape of a transmission waveform. For example, the transmission signal generator **14** includes a memory in which one or plural transmission waveforms are stored. The waveform can be selected by the control circuit **12** of the ultrasonic diagnostic apparatus main body **100**. Alternatively, whenever the transmission signal is generated, the waveform may be transferred from the ultrasonic diagnostic apparatus main body **100** through the cable **06** and stored.

The transmission/reception switching circuit **04** is configured to switch a signal path on the circuit when a transmission signal transmitted by the transmission circuit **03** and a reception signal which is an ultrasonic wave signal transmitted by the transducer **05** driven by the transmission signal and which is reflected from a target object are guided to the reception amplifier circuit **07**. In this way, the signal from the transmission circuit **03** can be transmitted to the transducer without being applied to the reception amplifier circuit **07**, and the signal from the subject can be guided to the reception amplifier circuit **07** through the transducer without being affected by the transmission circuit **03**.

The reception amplifier circuit **07** has a function of amplifying the ultrasonic wave signal obtained from the subject and changing the amplification factor each time.

The reception phasing circuit **08** has a function of forming beams similarly to the transmission phasing circuit **02**. The reception phasing circuit **08** is configured to adjust the timing of adding signals from all transducers obtaining signals from the subject so as to be different for each of the transducers when forming reception beams. The delay time for a transducer located closer to a focus position is increased to be greater than other transducers so as to match the timing of adding the reception signals obtained by transducers located farther from the focus position.

The signal processing circuit **09** and the image processing circuit **10** are configured to perform signal processing of converting the signal obtained through phasing addition into luminance information through wave detection or the like and perform coordinate conversion processing in accordance with the type of a probe through image signal processing as typified by γ processing. Here, the processed signal is displayed on the display monitor **11** as a diagnostic image.

Moreover, the above-described respective constituent circuits receive a principal clock signal from the control circuit **12**, and the timings of respective portions or the like are controlled. Specifically, transmission/reception switching is controlled and a diagnostic mode is switched.

Moreover, the power supply **13** is controlled by the control circuit **12** so as to generate various voltage values. Here, the generated voltage having various values is supplied to respective circuit units although not shown in the figure.

FIG. **4** shows a detailed block diagram of a characteristic portion of the invention.

The ultrasonic diagnostic apparatus shown in FIG. **4** includes the probe **01**, the ultrasonic diagnostic apparatus main body **100**, and the cable **06** connecting them together.

The transmission signal generator **14** is configured by a shift register, for example. Data may be written in advance to the shift register, and alternatively, data may be periodically transmitted from the ultrasonic diagnostic apparatus main body **100** through a data bus **101** and written to the shift register. Alternatively, a plurality of transmission waveforms may be written to the shift register or may be periodically transmitted by the ultrasonic diagnostic apparatus main body **100**, and the control circuit **12** may select one from the plurality of transmission waveforms.

The transmission circuit **03** receives a transmission signal which is generated and determined by the transmission signal generator **14**, amplifies the transmission signal, and drives the transducer **05**. The driving timing is determined by the transmission phasing circuit **02**.

In this embodiment, the transmission phasing circuit **02** is configured to include a delay memory **17**, a DLL circuit **18**, and a selector circuit **19**.

FIG. **5** illustrates the principle of transmission phasing. It is assumed that the transducer **05** is made up of an array of n transducers B**1** to Bn. If a focus point **16** of a beam is denoted by F, the distances from the respective transducers to the focus point F can be expressed as L**1** to Ln.

It is assumed that a transducer closest to the focus point among the n transducers is Bk, and the distance from the transducer to the focus point is Lk. The difference ΔLn of the distances from the respective transducers to the focus point F with reference to Lk can be expressed as follows.

$$\Delta Ln=Ln-Lk \quad \text{(Expression 1)}$$

In order to arrange the signals from the respective transducers at the focus point F so as to have the same phase, it is necessary to control the signal driving timings for each transducer while taking the difference ΔLn into account. Specifically, when the transducers Bk and Bn are driven at the same phase, a signal from the transducer Bn may be ΔLn ahead of the focus point F when a signal from the transducer Bk reaches the focus point F. Thus, it is necessary to advance the driving timing of the signal from the transducer Bn by a period corresponding to ΔLn.

Here, if the velocity of sound in a subject is vsound, the following expressions are obtained.

$$\Delta Ln=\Delta Tn\times v\text{sound} \quad \text{(Expression 2)}$$

$$\Delta Tn=M\times tclk+\Delta tn \quad \text{(Expression 3)}$$

Here, ΔTn is a sonic wave propagation time taken for a sonic wave to propagate from the respective transducers Bn to the focus point F, tclk is the cycle of a principal clock output from the control circuit **12** of the ultrasonic diagnostic apparatus main body, and M is an integer. Moreover, Δtn represents a period equal to or smaller than the principal clock cycle tclk.

In this example, since the transducer Bn is located farther from the focus point F by a distance of ΔLn than the reference transducer Bk, the transducer Bn needs to be driven earlier than the transducer Bk by an amount of ΔTn. The amount ΔTn corresponds to the sum of M principal clock intervals and Δtn in the ultrasonic diagnostic apparatus of the present embodiment.

Given the above, it is necessary to advance the operation timing of the transmission circuit **03** connected to the transducer Bn by an amount of ΔTn. Thus, the clock supplied to the transmission signal generator **14** configured, for example, by a shift register and connected to the transducer Bn may be moved forward by an amount of ΔTn as compared to that of the transducer Bk.

As a result, in order to transmit in-phase signals from a plurality of transducers to the same focus point **16**, it is necessary to apply a value in units of the principal clock tclk and a micro period equal to or smaller than the principal clock as a delay time. The delay time will be referred to as focus data.

$$\text{(Focus Data)}=\text{(Principal Clock)}\times M+\text{(Micro Delay)} \quad \text{(Expression 4)}$$

where, M=0, 1, 2, . . . integer

As shown in FIG. **4**, in the present embodiment, the delay amount in units of the principal clock is handled in the delay memory **17**. Similarly to transmission of data to the shift register, the delay amount may be written in advance to the delay memory **17**, and may be transmitted from the ultrasonic diagnostic apparatus main body **100** at arbitrary timing. The delay amount may be stored in advance in an internal memory (not shown) of the ultrasonic diagnostic apparatus main body **100**, and may be calculated in the control circuit **12**.

In addition, the control of the delay amount in units of the principal clock may not be performed depending on the position of the transmission focus. For example, when the focus position is located at a sufficient distance position as compared to the pitch of transducers, the time offset between the adjacent elements becomes equal to or smaller than the principal clock. Thus, it is not necessary to take a delay according to this degree of precision into account. In this case, 0 is stored in the delay memory **17** as delay data.

Since the delay data is different depending on the focus position, the control circuit **12** gives an instruction as to whether or not to use the data whenever focusing is performed.

Moreover, the micro delay which is a delay time equal to or smaller than the principal clock tclk is generated in the transmission phasing circuit **02**. A more preferred embodiment will be described with reference to the drawings.

FIG. **6** illustrates a method of creating a micro delay by way of a schematic diagram of a DLL (Delay Locked Loop) circuit. The DLL circuit includes a signal input portion **300** (Ckin), a phase comparator **301**, a delay control circuit **302**, and a variable delay circuit **303**. A delay amount of the variable delay circuit **303** is determined by a value that is output by the delay control circuit **302**.

The phase comparator **301** compares the phase of a signal input from the signal input portion **300** and the phase of a feedback signal **304** fed back from the variable delay circuit and outputs the comparison result to the delay control circuit **302**. The delay control circuit outputs the value held therein to the variable delay circuit **303** to thereby control the delay amount of the variable delay circuit **303**.

Moreover, the delay control circuit **302** controls the delay amount so as to eliminate a phase offset based on the comparison result output by the phase comparator **301**, between the phase of the signal input from a clock signal input portion **300** and the phase of the feedback signal **303**.

An example of the configuration of the variable delay circuit is also shown in FIG. **6**. In the figure, the variable delay circuit **303** delays the signal input from the signal input portion **300** using a chain of N series-connected by delay elements **305** configured by inverters, for example.

In the configuration of FIG. **6**, since there are N delay stages, it is possible to control the delay as finely as N divisions of the input clock (Ckin).

A more specific example will be described with reference to FIG. **7**.

FIG. **7** shows a case where the number of delay stages is 4. In FIG. **8**, CKin which is the clock signal input from the signal input portion **300** is shown on the top. Since there are four stages of delay elements, the respective delay elements can output the signals CKin with the phases shifted by 360°/4=90°. Therefore, as shown in FIG. **8**, the signals CK**1** to CK**3** are output with the phases shifted by 90°. When the input clock signal is a continuous wave, the signal CK**4** is output to be superimposed on the input signal.

A more preferred embodiment will be described with reference to FIG. **9**. FIG. **9** shows a state in which the transmission signal output from the shift register **14** described above is delayed. FIG. **9** shows a case in which waveform data for one cycle is stored in the shift register **14** as the transmission signal. Since the transmission signal is output in synchronization with the timing of the clock signal input to the shift register, in order to delay the transmission signal, the clock input to the shift register may be delayed.

It is assumed that a clock having a frequency four times the frequency f0 of the transmission signal is input to the signal input portion **300**. Here, as shown in FIG. **7**, when there are four delay elements, delay precision of f0×4×4 (16×f0) is obtained.

It is assumed that f0 is 5 MHz, and the sampling clock of the device is 20 MHz. In this case, the distance between the black circles in FIG. **9** is the principal clock of the device, and the maximum sampling cycle becomes 20 MHz. However, in the delay insertion configuration using the DLL, as shown in FIG. **8**, since it provides delay precision that is four times the principal clock, it is possible to provide delay precision of up to 16×f0=80 MHz. Thus, as shown in FIG. **9**, in this example, it is possible to provide a delay corresponding to a cycle that is four times finer than the sampling cycle of the device as denoted by the black circles. Thus, it is possible to realize a sensitive clock delay through the design of a DLL delay circuit, and the delay clock is supplied to the shift register **14** shown in FIG. **4**.

As described above, since the delay signal is obtained using the DLL circuit, it is not necessary to use a high-speed clock signal and it is possible to realize a transmission phasing function at a low cost and with a simple circuit configuration.

As described above, the delay amount is changed for each of all transducers used when forming beams. Thus, it is necessary to apply a unique value to each transducer. In the transmission phasing circuit **02** shown in FIG. **4**, it is necessary to realize an n-by-k matrix configuration where n is the number of connected transducers and k is the number of divisions for clock delay.

$$\text{(Number of Transducers:}n\text{)}\times\text{(Number of Clock Divisions:}k\text{)} \quad \text{(Expression 5)}$$

The output of the matrix constituting the selector circuit **19** is connected to the transmission signal generator **14** of each transducer as shown in FIG. **4**.

FIG. **10** shows an embodiment of creating a micro delay selection signal and a transmission sampling CLK.

The transmission signal delay process includes two steps. One is to apply a delay amount in unit of a system clock (the delay amount is stored in a memory area **200**) and the other is to apply a delay amount equal to or smaller than the unit of the system clock (the delay amount is stored in a memory area **201**).

The delay amount necessary for phasing the signals of each channel is calculated by a delay amount calculator **103** and the calculation results are stored in a delay memory **104**. Alternatively, the delay amount may be calculated by a system outside the ultrasonic diagnostic apparatus, and only the results thereof may be transmitted to the delay memory **104**. In the delay memory **104**, memory areas **200** and **201** for storing a delay (coarse delay) in units of the system CLK and a delay equal to or smaller than that of the system CLK are provided. This is only an example, and the respective values may not be stored in the memory, but may be maintained in a system. A transmission waveform sampling CLK generator **105** generates the sampling CLK of a transmission signal, and the sampling CLK is selected arbitrarily. For example, in order to generate a 2-MHz/3-wave transmission signal, at least six 4-MHz sampling CLKs are required. The number of clocks can be appropriately selected for each application as needed.

The transmission waveform sampling CLK generator **105** receives the delay data in units of the system CLK necessary for each channel from the delay memory **104** and generates a delayed waveform sampling CLK **106**.

The delayed waveform sampling CLK is input to the DLL circuit **18**. The DLL circuit **18** outputs a transmission sampling CLK to each channel at timings corresponding to the equal division of the system CLK by a predetermined phase division number K within one transmission CLK. Which timing signal will be obtained among the K divisions is determined based on data stored in the memory area **201** of the delay memory **104**. The value stored in the memory area **201** is normalized to the division number K of the system CLK by a normalizer **202** and transmitted to the selector circuit **19** as a micro delay selection signal **102**. In this way, a micro delay amount for each channel is selected, and as a result, the transmission waveform sampling CLK delayed in unit of the system CLK is output with a delay precision equal to or smaller than the unit of the system CLK unit. The CLK is input to the shift register **14**, and the transmission waveform data having been transmitted in advance thereto are read, whereby transmission waveforms delayed optimally for each channel can be generated.

Since the transmission circuit **03** is supposed to be built into the probe, a configuration in which only an NMOS transistor as shown in FIG. **10** is used can be considered, for example. The major part of the transmission circuit **03** includes an NMOS source follower and an NMOS switch that operates only at the falling edges.

Hereinabove, the invention has been described based on the configuration shown in FIG. **1**. In the present embodiment, the transmission circuit **03** can be provided uniquely to each transducer **05**. Moreover, since the transmission signal generator **14** and the transmission phasing circuit **02** can be formed at the same time, an analog signal cable through which the ultrasonic diagnostic apparatus main body **100** transmits a high-voltage transmission signal to the probe **01** as in the related art is not necessary.

## Second Embodiment

FIG. **2** shows the second embodiment of the invention. In the present embodiment, the reception amplifier circuit **07** is incorporated into the probe **01** together with the transmission circuit **03**.

In this case, the transmission circuit **03** and the reception amplifier circuit **07** can be provided uniquely to each transducer **05**.

## Third Embodiment

FIG. **3** shows the third embodiment of the invention. When the number of transducers **05** increases, so that it is difficult to transmit all signals output by the reception amplifier circuit **07** as described in the second embodiment to the ultrasonic diagnostic apparatus main body **100** through a cable, some of the signals output by the reception amplifier circuit **07** are added by an adder circuit **15** and transmitted to the main body **100**.

In the present embodiment, it is possible to decrease the number of transmission cables through which the probe **01** transmits signals to the ultrasonic diagnostic apparatus main body.

## Fourth Embodiment

FIG. **11** shows an example in which a transmission amplifier circuit which has the transmission phasing function according to the invention and can be incorporated into a probe is mounted on a CMUT (Capacitive Micromachined Ultrasonic Transducer).

The CMUT is configured to include a semiconductor substrate **401**, a thin film **402** made of semiconductor compounds, and a wall **403**, and a space surrounded by these elements is under vacuum or filled with a certain gas.

The CMUT has just the same electrical structure as a capacitor. A bias voltage is applied to the semiconductor substrate **401** and the semiconductor thin film **402** to produce an electric field, and the degree of tension of the semiconductor thin film **402** is controlled by the electric field. In this state, when an electrical signal having an ultrasonic frequency is applied, the thin film is excited, and ultrasonic waves corresponding to the magnitude of the applied bias voltage are excited by an electroacoustic conversion effect.

A semiconductor substrate **401** in which the proposed circuit is mounted under the electrode on the lower side of the semiconductor substrate shown in FIG. **11** is produced by a semiconductor circuit manufacturing method. For example, a signal line **404** or the like on the lower surface of the circuit substrate is connected to the ultrasonic diagnostic apparatus main body through a cable.

As in the present embodiment, when the invention is applied to a probe as typified by the CMUT, manufactured by a semiconductor manufacturing method, it is possible to easily integrate and mount the proposed circuit.

## REFERENCE SIGNS LIST

**01** Probe
**02** Transmission Phasing Circuit
**03** Transmission Circuit
**04** Transmission/Reception Switching Circuit
**05** Transducer
**06** Probe Cable
**07** Reception Amplifier Circuit
**08** Reception Phasing Circuit
**09** Signal Processing Circuit
**10** Image Processing Circuit
**11** Display Monitor
**12** Control Circuit
**13** Power Supply
**14** Transmission Signal Generator
**15** Adder Circuit
**16** Focus Point F
**17** Delay Memory
**18** DLL Circuit
**19** Selector Circuit
**100** Ultrasonic Diagnostic Apparatus Main Body
**101** Data Bus
**102** Micro Delay Selection Signal

**103** Delay Amount Calculator
**104** Delay Memory
**105** Transmission Waveform Sampling CLK Generator
**106** Transmission Waveform Sampling CLK
**200** Memory Area Equivalent to CLK Unit
**201** Memory Area Smaller Than CLK Unit
**202** Normalizer
**300** Signal Input Portion
**301** Phase Comparator
**302** Delay Control Circuit
**303** Variable Delay Circuit
**304** Feedback Signal
**305** Delay Element
**401** Semiconductor Substrate
**402** Thin Film
**403** Wall
**404** Signal Line

The invention claimed is:

**1**. An ultrasonic diagnostic apparatus comprising:

a probe which has a transducer and which transmits and receives ultrasonic waves; and

an ultrasonic diagnostic apparatus main body,

wherein signals are transmitted and received between the ultrasonic diagnostic apparatus main body and the probe,

wherein the probe includes a transmission signal generator that generates an ultrasonic transmission signal, a transmission circuit that amplifies the generated transmission signal, and a transmission phasing circuit that adjusts the timing of the transmission signal, and

wherein the transmission phasing circuit includes a DLL (Delay Locked Loop) circuit that generates a micro delay less than or equal to the cycle of a transmission clock signal and a selector circuit that selects and outputs the output of the DLL circuit.

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

wherein the probe includes a plurality of transducers, and

wherein transmission signal generator, the transmission circuit, and the transmission phasing circuit are independently provided to each transducer.

**3**. The ultrasonic diagnostic apparatus according to claim **1**, wherein the signals are transmitted and received between the ultrasonic diagnostic apparatus main body and the probe through a digital transmission cable or wireless transmission.

**4**. The ultrasonic diagnostic apparatus according to claim **1**, wherein the transmission signal generator has a memory for storing transmission signal waveforms.

**5**. The ultrasonic diagnostic apparatus according to claim **4**, wherein the memory for storing the transmission signal waveforms is a shift register.

**6**. The ultrasonic diagnostic apparatus according to claim **1**, wherein a reception amplifier circuit is incorporated into the probe.

**7**. The ultrasonic diagnostic apparatus according to claim **6**, wherein the output of the reception amplifier circuit is added by an adder circuit and transmitted to the ultrasonic diagnostic apparatus main body.

**8**. The ultrasonic diagnostic apparatus according to claim **1**, wherein the transducer is a CMUT (Capacitive Micromachined Ultrasonic Transducer).

**9**. The ultrasonic diagnostic apparatus according to claim **8**, wherein the transmission signal generator, the transmission circuit, and the transmission phasing circuit are mounted on a substrate of the CMUT by a semiconductor circuit manufacturing method.

**10**. An ultrasonic diagnostic apparatus comprising:

a probe which has a transducer and which transmits and receives ultrasonic waves; and

an ultrasonic diagnostic apparatus main body,

wherein signals are transmitted and received between the ultrasonic diagnostic apparatus main body and the probe,

wherein the probe includes a transmission signal generator that generates an ultrasonic transmission signal, a transmission circuit that amplifies the generated transmission signal, and a transmission phasing circuit that adjusts the timing of the transmission signal, and

wherein the transmission phasing circuit includes a delay memory that stores a delay amount in unit of a principal clock, a DLL (Delay Locked Loop) circuit that generates a micro delay less than or equal to the principal clock, and a selector circuit that selects and outputs the output of the DLL circuit.

**11**. The ultrasonic diagnostic apparatus according to claim **10**, wherein the DLL circuit includes a phase comparator, a delay control circuit, and a variable delay circuit, the phase comparator compares the phase of an input signal and the phase of the output of the variable delay circuit, the delay control circuit receives the result of comparison by the phase comparator and controls a delay amount of the variable delay circuit, and the variable delay circuit delays the input signal in accordance with the output of the delay control circuit.

**12**. The ultrasonic diagnostic apparatus according to claim **11**, wherein the variable delay circuit includes a plurality of series-connected inverters and outputs the delay signal as the output of the respective inverters.

**13**. A ultrasonic diagnostic method comprising:

transmitting and receiving ultrasonic waves by a transducer in a probe;

transferring signals between the probe and an ultrasonic diagnostic apparatus main body;

generating an ultrasonic transmission signal within the probe;

adjusting, by a transmission phasing circuit, the timing of the transmission signal, the transmission phasing circuit including a DLL (Delay Locked Loop) circuit and a selector circuit;

generating, by the DLL circuit, a micro delay less than or equal to the cycle of a transmission clock signal;

selecting and outputting, by the selector circuit, the output of the DLL circuit; and

amplifying the transmission signal of which the timing is adjusted.

* * * * *

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摘要(译)

一种超声波诊断装置，其特征在于，具有探头，该探头具有用于发送和接收超声波的换能器，超声波诊断装置主体;在超声诊断设备主体和探头之间通过其传输和接收信号的电缆，其中探头包括产生超声传输信号的传输信号发生器，放大产生的传输信号的传输电路，以及传输定相调整传输信号时序的电路。