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(54) **ULTRASONIC DIAGNOSTIC APPARATUS**

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(58) **Field of Classification Search**

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See application file for complete search history.

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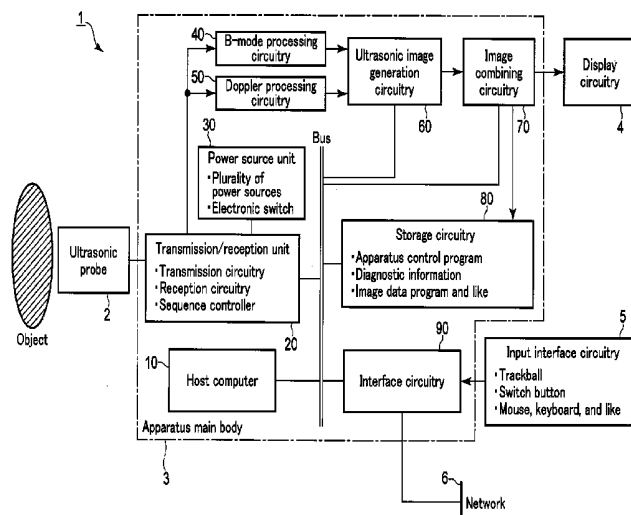
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(57) **ABSTRACT**

In general, according to one embodiment, an ultrasonic diagnostic apparatus includes an ultrasonic probe, a plurality of power supplies implemented by circuitry, at least one pulser, and a controller implemented by circuitry. The ultrasonic probe includes a plurality of piezoelectric transducers which generate ultrasonic waves in response to supplied driving signals. The pulser outputs the driving signal based on an applied voltage applied from any one of the plurality of power supplies. The controller switches the plurality of power supplies in accordance with the at least one pulser used for generation of the driving signal in one transmission mode period.

12 Claims, 7 Drawing Sheets



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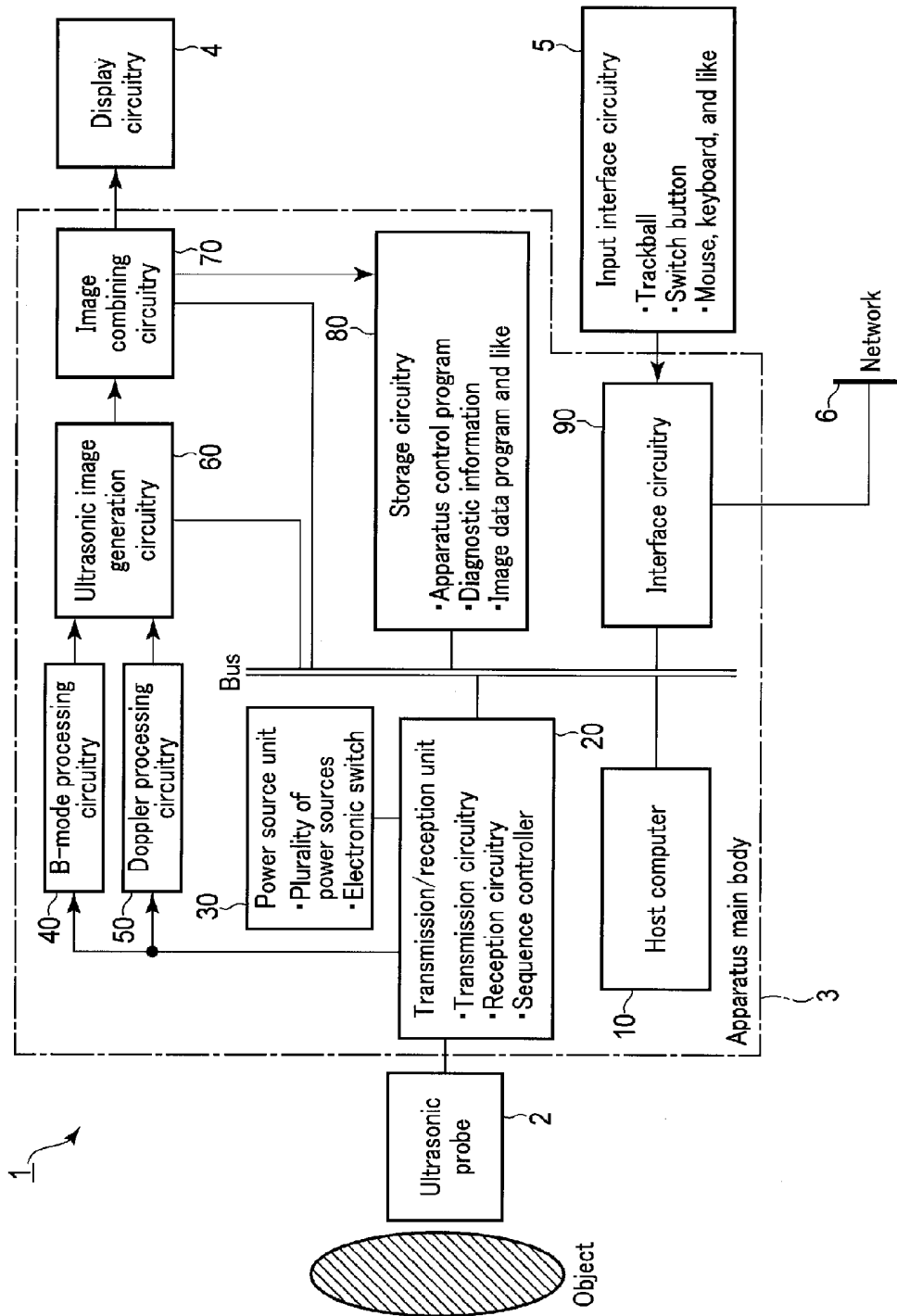


FIG. 1

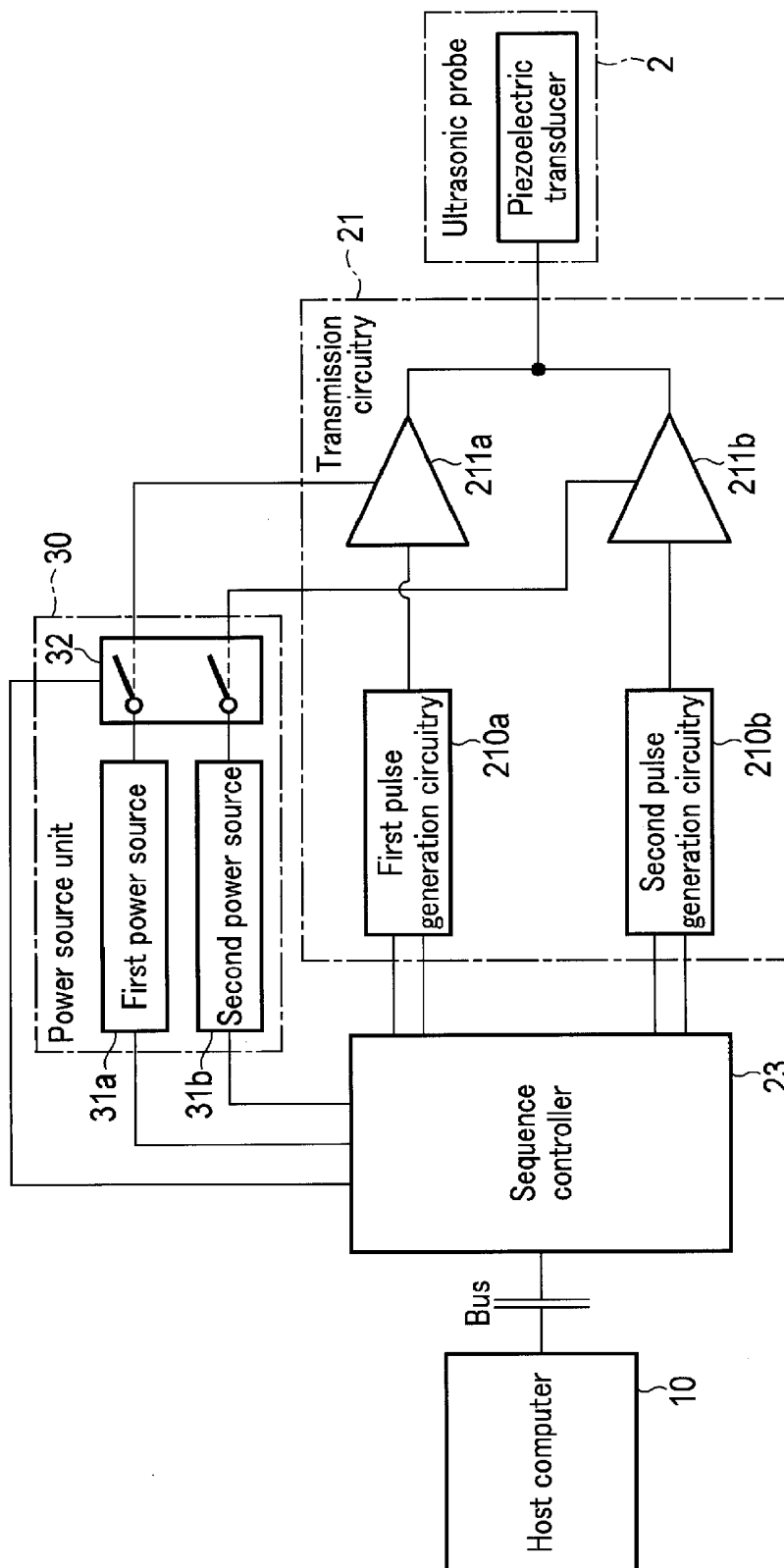
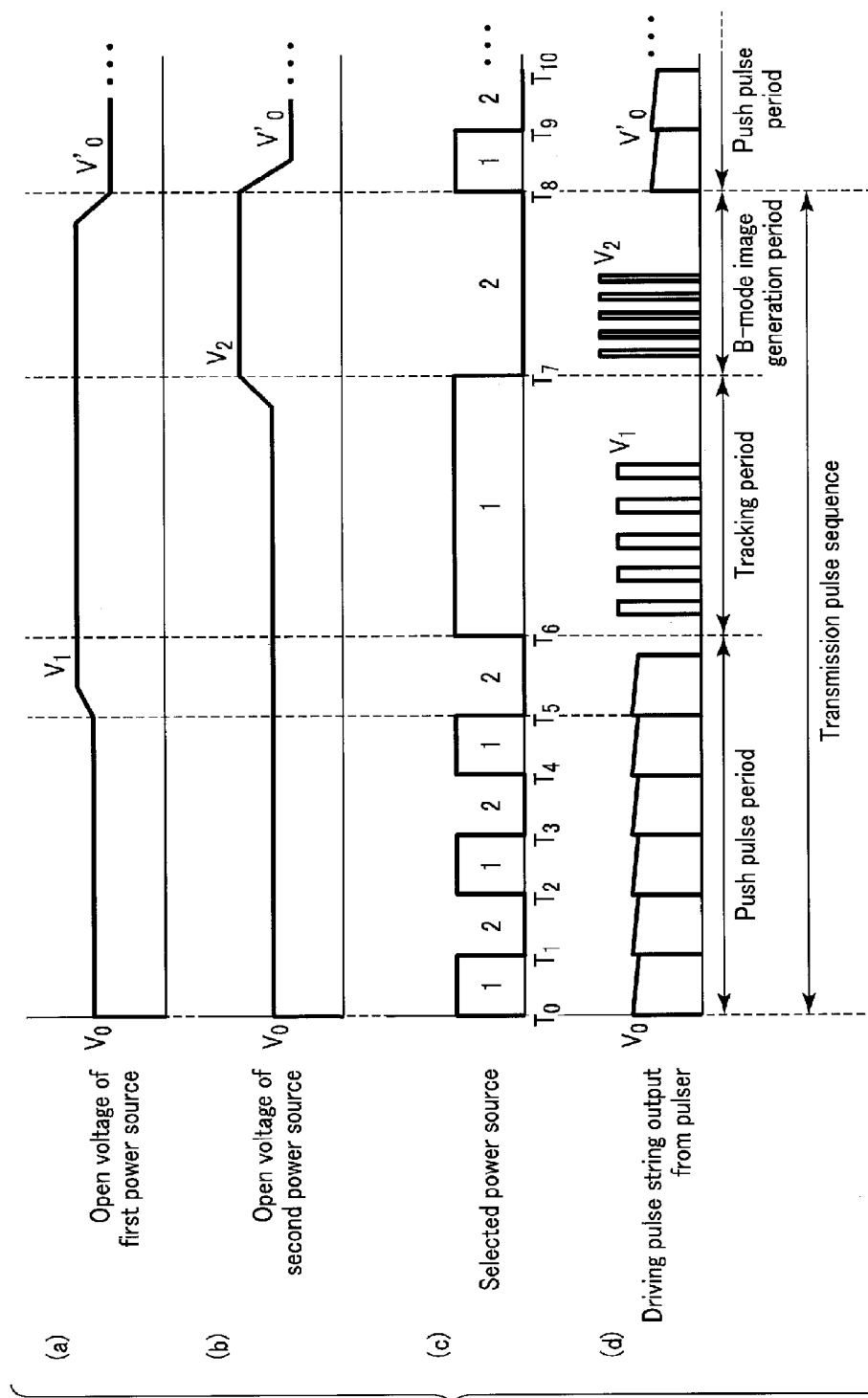


FIG. 2



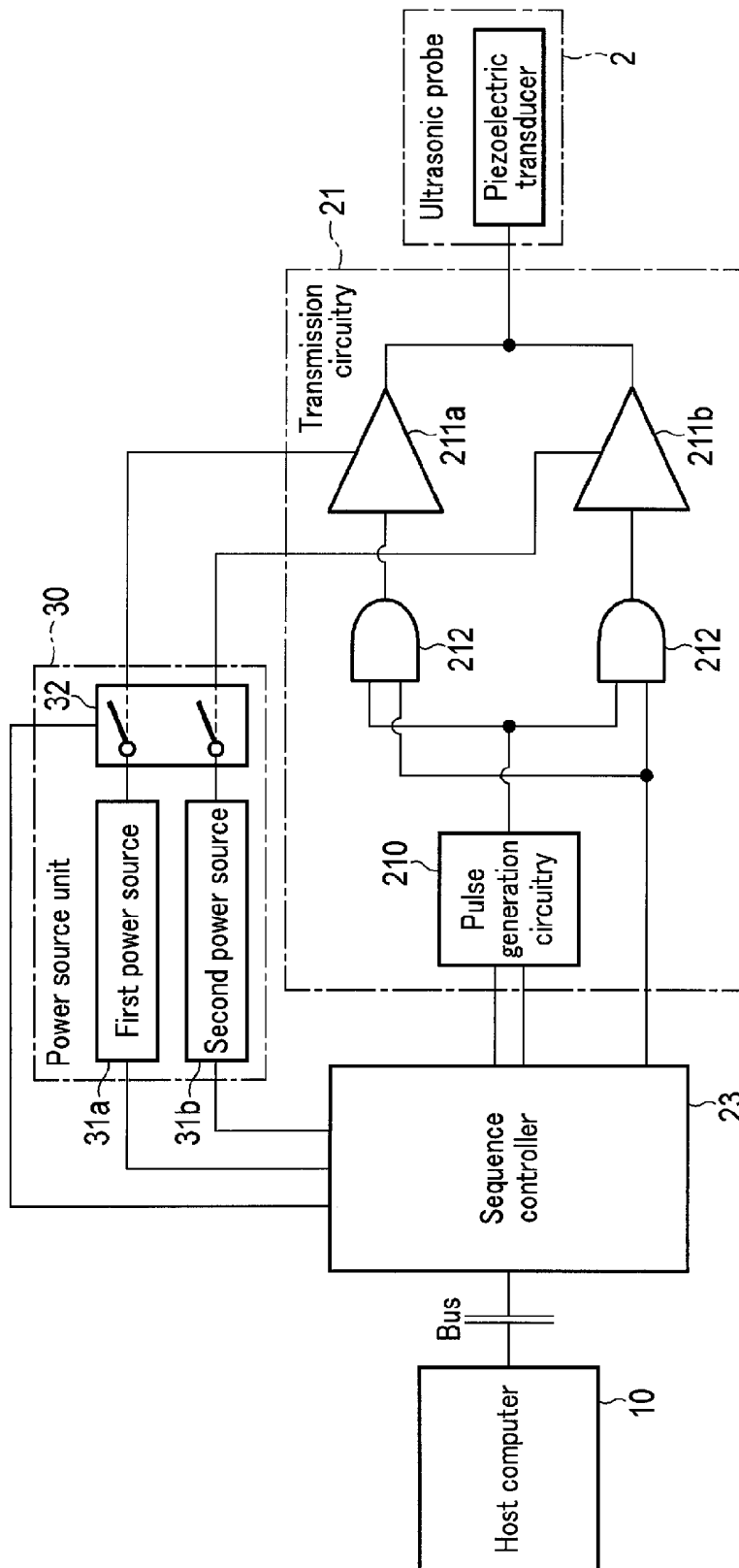


FIG. 4

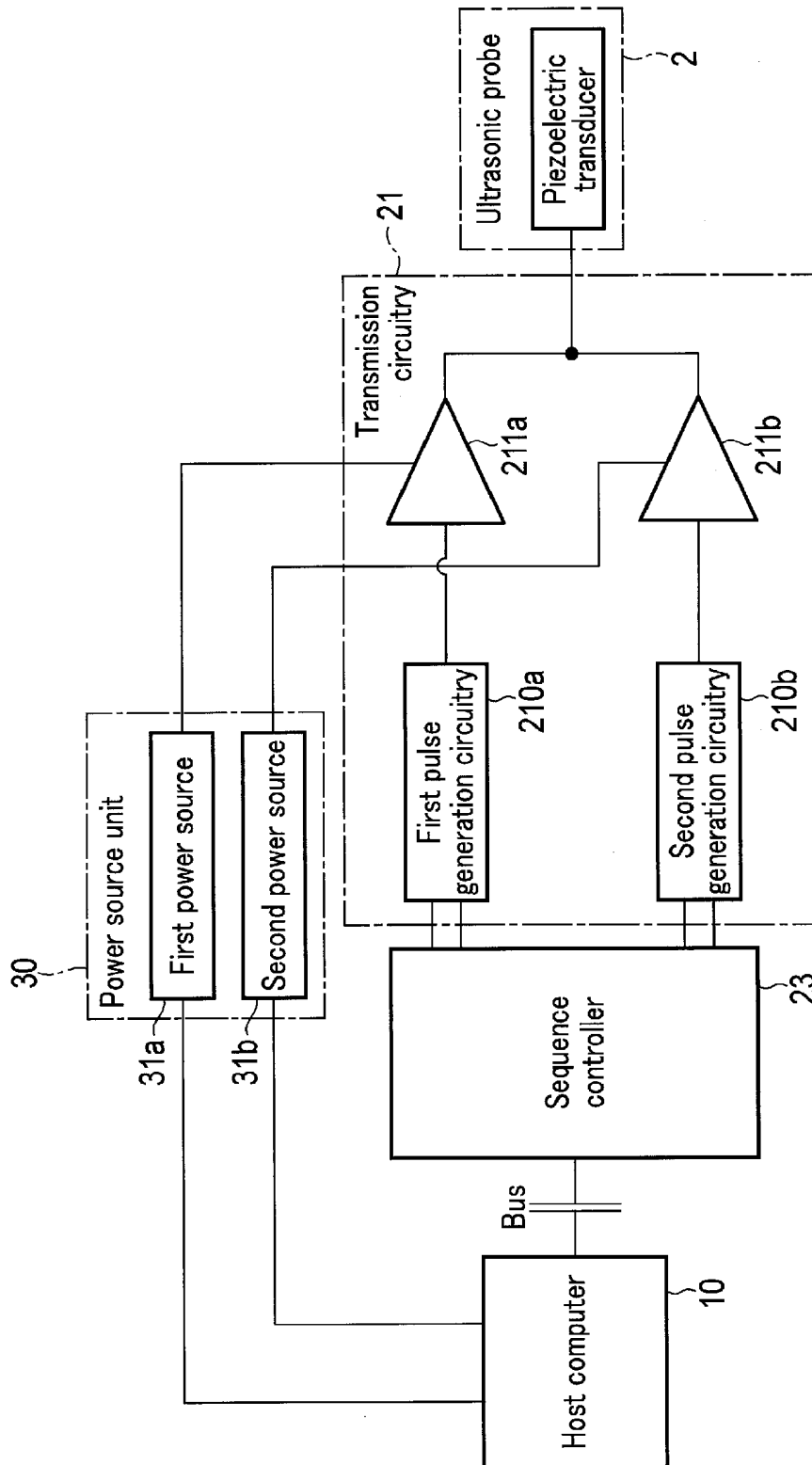


FIG. 5

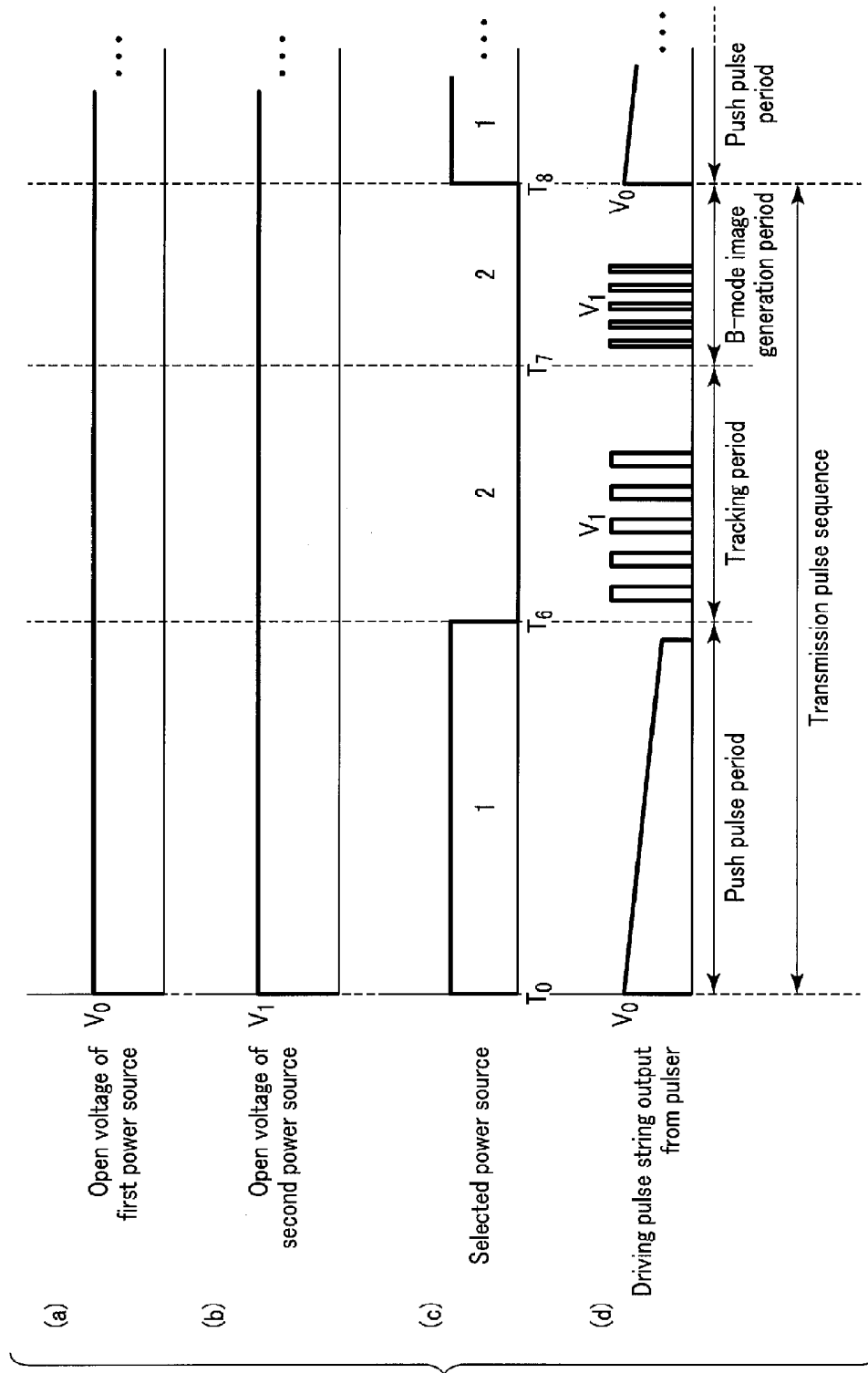


FIG. 6

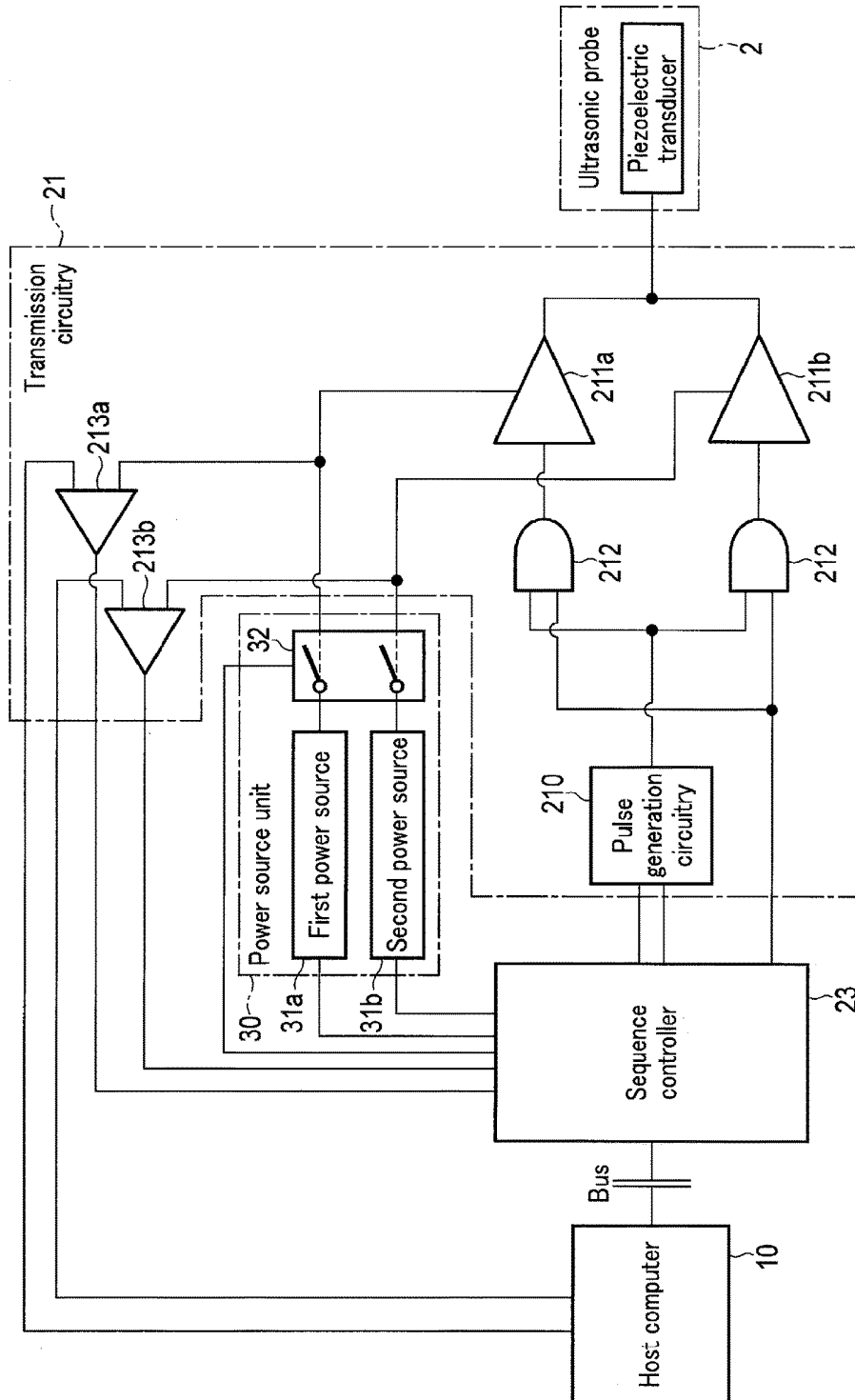


FIG. 7

ULTRASONIC DIAGNOSTIC APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2014-205968, filed Oct. 6, 2014 the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to an ultrasonic diagnostic apparatus which images a region scanned with ultrasonic waves in an object, and implements, for example, shear wave elastography of diagnosing the hardness of living organs such as the liver, the breasts, and the like, a drug delivery system which quantitatively and spatially controls the internal distribution of the drug administered into an object by irradiation with ultrasonic waves, and the like.

BACKGROUND

In the field of ultrasonic diagnosis, for example, the elastography diagnosis of diagnosing hardness is performed in actual medical practice. Elastography diagnosis is the diagnostic method of diagnosing that a given tissue is harder than a normal region because of hepatic cirrhosis or fibrosis or calcification of the tissue. In general, an examiner irradiates an object with ultrasonic waves while repeatedly pressing and releasing the object by moving an ultrasonic probe with his/her hand. Diagnosis of hardness is performed by analyzing reflected waves from a living tissue. The method of repeating such pressing and releasing action has problems, for example, that measured values vary depending on the way of moving the probe and different examiners obtain different results.

Recently, attention has been paid to a technique called shear wave elastography. First of all, shear waves are generated from a living body by irradiating an object with relatively strong ultrasonic waves (push pulses) from an ultrasonic probe. The propagation velocity of the shear waves is measured with tracking pulses output from the ultrasonic probe. The result is analyzed and visualized. The resultant image is then superimposed on a B-mode image to perform diagnosis of hardness. Unlike general elastography, shear wave elastography needs not repeat pressing and releasing action, and hence can implement measurement with more ease and higher reproducibility.

To generate such push pulses in shear wave elastography, a driving pulse string (driving signal) having a high peak value of 100 V or the like is used. An applied high voltage (for example, 100 V) is required to generate a driving pulse string having a high peak value. If, however, a high voltage is applied to a pulser, a transmission power source lacks in charge (that is, charge accumulated in the capacitor in the transmission power source). This often leads to a droop in applied voltage (a drop in voltage) to the pulser relative to the set voltage (open voltage) of the transmission power source.

On the other hand, in the field of ultrasonic diagnosis, for example, a DDS (Drug Delivery System) is used in actual medical practice. In this system, a drug capsule is administered to an object in advance, and an operator such as a doctor intentionally breaks the drug capsule in the body by irradiating the capsule with relatively strong ultrasonic

waves from an ultrasonic probe of an ultrasonic diagnostic apparatus. It is then possible to quantitatively and spatially control the internal distribution of the drug in the object by using the breakage of the capsule. In addition, using an ultrasonic diagnostic apparatus can simultaneously perform diagnosis and the breakage of a drug capsule.

In the use of a drug delivery system, a driving pulse string having a high peak value is used even when such relatively strong ultrasonic waves are applied. To generate a driving pulse string having a high peak value, an applied high voltage (for example, 100 V) is required. For this reason, like the above shear wave elastography, the above technique has often the problem of the occurrence of voltage droops.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram representing an example of the arrangement of an ultrasonic diagnostic apparatus according to the first embodiment;

FIG. 2 is a block diagram representing an example of transmission circuitry according to the first embodiment;

FIG. 3 represents an example of timing charts representing an ultrasonic transmission/reception sequence using a power switching function in shear wave elastography according to the first embodiment;

FIG. 4 is a block diagram representing a modification of transmission circuitry using logic gates according to the first embodiment;

FIG. 5 is a block diagram representing an example of transmission circuitry in a conventional ultrasonic diagnostic apparatus;

FIG. 6 represents an example of timing charts representing an ultrasonic transmission/reception sequence in shear wave elastography using a conventional ultrasonic diagnostic apparatus; and

FIG. 7 is a block diagram representing an example of transmission circuitry according to the second embodiment.

DETAILED DESCRIPTION

In general, according to one embodiment, an ultrasonic diagnostic apparatus includes an ultrasonic probe, a plurality of power supplies implemented by circuitry, at least one pulser, and a controller implemented by circuitry. The ultrasonic probe includes a plurality of piezoelectric transducers which generate ultrasonic waves in response to supplied driving signals. The pulser outputs the driving signal based on an applied voltage applied from any one of the plurality of power supplies. The controller switches the plurality of power supplies in accordance with the at least one pulser used for generation of the driving signal in one transmission mode period.

The embodiments will be described below with reference to the accompanying drawing. The same reference numerals in the following description denote the same constituent elements having almost the same arrangements, and a repetitive description will be omitted.

(First Embodiment)

FIG. 1 represents the arrangement of an ultrasonic diagnostic apparatus 1 according to the first embodiment. The ultrasonic diagnostic apparatus 1 includes an ultrasonic probe 2, an apparatus main body 3, display circuitry 4 (a monitor or display), and input interface circuitry 5. In addition, a network 6 capable of external communication may be connected to the ultrasonic diagnostic apparatus 1 via interface circuitry 90 of the apparatus main body 3.

The ultrasonic probe **2** includes a plurality of piezoelectric transducers, a matching layer, and a backing member provided on the back surface side of the plurality of piezoelectric transducers. The plurality of piezoelectric transducers are acoustoelectric reversible conversion elements such as piezoelectric ceramic elements. The plurality of piezoelectric transducers are arranged in parallel and mounted on the distal end of the ultrasonic probe **2**. Each piezoelectric transducer generates an ultrasonic wave in response to the driving pulse string (driving signal) transmitted and supplied from a transmission/reception unit **20** (to be described later).

When an object is irradiated with ultrasonic waves via the ultrasonic probe **2**, the ultrasonic waves with which the object are irradiated are reflected by a discontinuity surface of acoustic impedance of a living body tissue in the object. The piezoelectric transducers receive the reflected ultrasonic waves and generate an echo signal. The amplitude of this echo signal depends on an acoustic impedance difference on the discontinuity surface as a boundary concerning the reflection of the ultrasonic waves. Identical piezoelectric transducers may be selectively used as a piezoelectric transducer (for transmission) for the generation of ultrasonic waves and a piezoelectric transducer (for reception) for the generation of echo signals by deciding a transmission timing and a reception timing when, for example, irradiating an object with discrete ultrasonic waves (pulse waves). Alternatively, for example, when irradiating an object with a continuous ultrasonic wave (continuous wave), this apparatus may separately include piezoelectric transducers for transmission and piezoelectric transducers for reception. The frequency of the echo signal generated when transmission ultrasonic waves are reflected by a moving blood flow, the surface of the cardiac wall, or the like is subjected to a frequency shift depending on the velocity component of the moving body (the blood flow and the surface of the cardiac wall) in the ultrasonic transmission direction due to the Doppler effect.

The apparatus main body **3** includes a host computer **10**, a transmission/reception unit **20**, a power source unit **30**, B-mode processing circuitry **40**, Doppler processing circuitry **50**, ultrasonic image generation circuitry **60**, image combining circuitry **70**, storage circuitry **80** (a memory), and interface circuitry **90**.

The host computer **10** includes a processor such as a CPU (Central Processing Unit) and is mainly in charge of controlling the overall operation of the ultrasonic diagnostic apparatus **1**. Note that a specific operation of the host computer **10** will be described later in association with a description of other portions.

The transmission/reception unit **20** includes transmission circuitry and a sequence controller (implemented by circuitry). The transmission circuitry and the sequence controller are denoted by reference numerals in FIG. **2** and subsequent figures and will be described in detail later. The transmission circuitry transmits driving pulse strings to the respective piezoelectric transducers of the ultrasonic probe **2**. The reception circuitry generates a reception signal based on the echo signal generated by each piezoelectric transducer.

Driving pulse strings transmitted to the respective piezoelectric transducers also differ in the respective periods in an ultrasonic transmission/reception sequence (For example, a sequence constituted by three periods, i.e., a push pulse transmission period, a tracking period, and a B-mode image generation period). In these periods, control having a high time resolution (e.g., on the order of several ten μ s to several hundred μ s) is required. The sequence controller has a higher

time resolution than the host computer **10** configured to mainly perform software processing by using CPU, and executes control of a sequence requiring the high time resolution. An operation mode of the ultrasonic diagnostic apparatus **1** which transmits strong ultrasonic waves such as push pulses will be referred to as a transmission mode.

The power source unit **30** includes a plurality of power source circuits (to be simply referred to as power sources hereinafter: note that FIG. **2** (to be described later) exemplarily represents two power sources, i.e., a first power source **31a** and a second power source **31b**) and an electronic switch (ON/OFF switching means) which switches between executing and stopping voltage application from the plurality of power sources. Note that a detailed operation will be described again with reference to FIG. **2**.

The B-mode processing circuitry **40** includes an envelope detector and a logarithmic converter. The envelope detector executes envelope detection of the reception signal output from the reception circuitry. The envelope detector outputs the envelope-detected signal to the logarithmic converter. The logarithmic converter relatively enhances a weak signal by logarithmically converting the envelope-detected signal. The B-mode processing circuitry **40** generates a signal value for each depth on each scanning line and each ultrasonic transmission/reception based on the signal enhanced by the logarithmic converter. Note that the B-mode processing circuitry **40** may generate volume data instead of a signal value for each depth on each scanning line and each ultrasonic transmission/reception. The data generated by the B-mode processing circuitry **40** will be collectively referred to as B-mode data hereinafter.

The Doppler processing circuitry **50** includes a mixer, an LPF (Low Pass Filter), and a velocity/variance/power computation device. The mixer multiplies the reception signal output from the reception circuitry by a reference signal having a frequency f_0 equal to the transmission frequency. This multiplication obtains a signal having a component with a Doppler shift frequency f_d and a signal having a frequency component of $(2f_0 + f_d)$. The LPF removes a signal of a high-frequency component $(2f_0 + f_d)$ from a signal having two types of frequency components from the mixer. The Doppler processing circuitry **50** generates a Doppler signal having the component with the Doppler shift frequency f_d by removing the signal of the high-frequency component $(2f_0 + f_d)$.

Note that the Doppler processing circuitry **50** may use a quadrature detection scheme to generate Doppler signals. In this case, the Doppler processing circuitry **50** performs quadrature detection to convert a reception signal (RF signal) into an IQ signal. The Doppler processing circuitry **50** generates a Doppler signal having the Doppler shift frequency f_d by performing complex Fourier transform of the IQ signal. Doppler signals are, for example, Doppler components based on a blood flow, tissue, and contrast medium. The velocity/variance/power computation device includes an MTI (Moving Target Indicator) filter, an LPF filter, and an autocorrelation computation device. Note that this device may include a cross-correlation computation device instead of the autocorrelation computation device. The MTI filter removes a Doppler component (a clutter component) caused by the respiratory movement or pulsatory movement of an organ or the like from a generated Doppler signal. The MTI filter is used to extract a Doppler component concerning a blood flow from a Doppler signal. The LPF is used to extract a Doppler component concerning the movement of the tissue from a Doppler signal.

The ultrasonic image generation circuitry **60** includes a DSC (Digital Scan Converter) and an image memory. The ultrasonic image generation circuitry **60** executes coordinate conversion processing (resampling) for the DSC. Coordinate conversion processing is to convert, for example, a scanning line signal string for ultrasonic scanning, which is formed from B-mode data, Doppler data, and propagation time data, into a scanning line signal string in a general video format typified by a TV format. The ultrasonic image generation circuitry **60** generates an ultrasonic image as a display image by executing coordinate conversion processing. More specifically, the ultrasonic image generation circuitry **60** generates a B-mode image based on B-mode data. The ultrasonic image generation circuitry **60** generates a Doppler image such as an average velocity image, a variance image, or a power image based on Doppler data.

The ultrasonic image generation circuitry **60** generates a shear wave propagation image assigned with a hue in accordance with the propagation time at each position in a predetermined region based on propagation time data and the propagation time hue correspondence table stored in the storage circuitry **80**. The propagation time hue correspondence table is a correspondence table of hues corresponding to propagation time values. For example, a hue corresponding to a propagation time of 0 is blue. For example, hues are defined as blue, blue green, green, yellow green, yellow, orange, and red in the order named with an increase in propagation time, with the maximum propagation time corresponding to red.

The image combining circuitry **70** combines character information of various types of parameters, scale marks, and the like with ultrasonic images. The image combining circuitry **70** generates a superimposed image by superimposing a shear wave propagation image on a B-mode image upon alignment.

The storage circuitry **80** stores a plurality of reception delay patterns with different focus depths, a plurality of transmission delay patterns, a plurality of shear wave generation transmission delay patterns, control programs for the ultrasonic diagnostic apparatus **1**, a diagnostic program, various types of data groups such as transmission/reception conditions, diagnostic information (patient IDs, findings by doctors, and the like), the reception signals generated by the reception circuitry, the B-mode data generated by the B-mode processing circuitry **40**, the Doppler data generated by the Doppler processing circuitry **50**, first and second displacement data at each position in a predetermined region, body motion displacement data, shear wave propagation data, a propagation time hue correspondence table, B-mode images, average velocity images, variance images, power images, shear wave propagation images, an algorithm (to be referred to as a shear wave propagation image generation algorithm hereinafter) concerning the generation of shear wave propagation images, and the like. In addition, the storage circuitry **80** includes a memory (not represented) and stores data (to be referred to as image data hereinafter) corresponding to generated ultrasonic images (B-mode images, average velocity images, variance images, power images, and shear wave propagation images). Image data stored in the memory is read out in accordance with an instruction from the operator via the input interface circuitry **5** (to be described later). This memory is, for example, a memory which stores ultrasonic images corresponding to a plurality of frames immediately before freezing. Continuously displaying (cine displaying) the images stored in this cine memory can display a moving ultrasonic image on the display circuitry **4** (to be described later). The host computer

10 executes the above programs stored in the storage circuitry **80**. The host computer **10** executes write/read of the above data and the like to/from the memory.

The interface circuitry **90** is an interface concerning the input interface circuitry **5** and the network **6**. Data such as the ultrasonic images, the analysis results, and the like, which are obtained by the apparatus main body **3**, can be transferred to other apparatuses via the interface circuitry **90** and the network **6**. Note that the interface circuitry **90** can also download, via the network **6**, medical images concerning objects acquired by other medical image diagnostic apparatuses.

The display circuitry **4** displays a B-mode image, an ultrasonic image such as a Doppler image, a shear wave propagation image, a superimposed image, or the like based on an output from the image combining circuitry **70**. Note that the display circuitry **4** may execute adjustment such as brightness correction, contrast correction, dynamic range correction, and γ correction and color mapping with respect to a displayed image.

The input interface circuitry **5** is connected to the interface circuitry **90** to input, to the apparatus main body **3**, various types of instructions, commands, information, selections, and settings from an operator such as a doctor. The input interface circuitry **5** includes input devices such as a trackball, switch buttons, a mouse, and a keyboard. These input devices detect the coordinates of the cursor displayed on the display screen and output the detected coordinates to the host computer **10**. Note that the input device may be a touch command screen provided to cover the display screen. In this case, the input interface circuitry **5** detects touched and designated coordinates by a coordinate reading principle such as an electromagnetic induction scheme, magnetostrictive scheme, or a pressure-sensitive scheme, and outputs the detected coordinates to the host computer **10**. When, for example, the operator operates the end button or freeze button of the input interface circuitry **5**, the ultrasonic transmission/reception is terminated, and the apparatus main body **3** is set in a pause state.

In addition, the input interface circuitry **5** accepts an ROI (Region of Interest) input by the operator or a predetermined region on which the operator focuses attention. The input interface circuitry **5** accepts the input of the mode selected by the operator.

FIG. **2** is a block diagram representing an example of transmission circuitry **21** according to the first embodiment. FIG. **2** represents the ultrasonic probe **2**, the host computer **10**, a sequence controller **23**, the power source unit **30** (power sources (the first power source **31a** and the second power source **31b**) and an electronic switch **32**) in association with the transmission circuitry **21**. The transmission circuitry **21** includes pulse generation circuitry (first pulse generation circuitry **210a** and second pulse generation circuitry **210b**) and pulsers (a first pulser **211a** and a second pulser **211b**). Although FIG. **2** represents the single transmission circuitry **21**, a plurality of transmission circuits **21** are provided in practice. A general arrangement is configured to selectively switch between a plurality of transducers connected to one transmission circuitry.

The first power source **31a** is connected to a first pulser **211a** to apply the voltage required for the generation of a driving pulse string to the first pulser **211a**. Likewise, the second power source **31b** is connected to a second pulser **211b** to apply the voltage required for the generation of a driving pulse string to the second pulser **211b**. The electronic switch **32** switches between executing and stopping the

application of a voltage from the first power source **31a** or the second power source **31b**.

Note that, for example, a mechanical switch may be provided in place of the electronic switch **32**. FIG. **2** separately represents the electronic switch **32** and the power sources. In practice, however, the electronic switch **32** may be designed separately from the power sources or may be designed to be incorporated in the power source circuitry.

The sequence controller **23** is connected to the transmission circuitry **21** and the power source unit **30** to control the operation of the transmission circuitry **21** and the operation of the power source unit **30** with high time resolutions on the order of several ten μ s to several hundred μ s. The sequence controller **23** transmits clock signals (clocks or clock pulses) based on the time resolutions to the first pulse generation circuitry **210a** and the second pulse generation circuitry **210b**. The first pulse generation circuitry **210a** and the second pulse generation circuitry **210b** generate excitation pulse strings by phase controllably frequency-dividing clock signals from the sequence controller **23**. The first pulse generation circuitry **210a** transmits the excitation pulse string to the first pulser **211a** connected to the first pulse generation circuitry **210a**. Likewise, the second pulse generation circuitry **210b** transmits the excitation pulse string to the second pulser **211b** connected to the second pulse generation circuitry **210b**.

The first pulser **211a** and the second pulser **211b** are respectively connected to the first power source **31a** and the second power source **31b** via the electronic switch **32**.

That is, these pulsers form two signal systems, each including one power source and one pulser. The first pulser **211a** generates a driving pulse string by amplifying an excitation pulse string in accordance with an applied voltage from the first power source **31a**, and transmits the driving pulse string to the piezoelectric transducers of the ultrasonic probe **2**. The first pulser **211a** transmits no signal when an applied voltage from the first power source **31a** is stopped by the electronic switch **32**. Likewise, the second pulser **211b** generates a driving pulse string by amplifying an excitation pulse string in accordance with an applied voltage from the second power source **31b**, and transmits the driving pulse string to the piezoelectric transducers of the ultrasonic probe **2**. The first second pulser **211b** transmits no signal when an applied voltage from the second power source **31b** is stopped by the electronic switch **32**.

Note that in order to avoid redundancy, refer to the description made with reference to FIG. **1** for the operations of the ultrasonic probe **2** and the host computer **10** in FIG. **2**.

The power switching function of the ultrasonic diagnostic apparatus **1** according to this embodiment will be described next.

The sequence controller **23** exclusively (alternatively or alternately) selects a power source (the first power source **31a** or the second power source **31b**) to apply a voltage to a pulser (the first pulser **211a** or the second pulser **211b**) by switching the electronic switch **32** in a transmission mode period (e.g., a period during which push pulses are transmitted to generate shear waves from an object) (power source switching function). This is merely an example and is not exhaustive. The power source (e.g., the first power source **31a**) selected by the sequence controller **23** applies a voltage to a pulser (e.g., the first pulser **211a**) in a selected period. The power source (e.g., the second power source **31b**) which is not selected by the sequence controller **23** applies no voltage to a pulser (e.g., the second pulser **211b**) in a period during which the power source is not selected.

The sequence controller **23** may switch the electronic switch **32** at the time intervals set in advance by a doctor or the like or may switch the electronic switch **32** for each pulse output count set in advance by an operator such as a doctor (open loop control).

A power source which is not selected will be referred to as an inactive power source. The sequence controller **23** executes control to change the value of the open voltage of an inactive power source.

FIG. **3** represents timing charts representing a transmission pulse sequence using the power source switching function in shear wave elastography according to the first embodiment. Assume that the transmission pulse sequence in this shear wave elastography is the sequence constituted by a push pulse period, a tracking period, and a B-mode image generation period in the order named.

FIG. **3** represents four timing charts (a) to (d) in order from the top. In FIG. **3**, (a) represents a temporal change in the open voltage of the first power source **31a**. In FIG. **3**, (b) represents a temporal change in the open voltage of the second power source **31b**. In FIG. **3**, (c) represents a temporal change of a power source selected by the sequence controller **23**. That is, "1" in (c) in FIG. **3** represents a state in which the first power source **31a** is selected. In FIG. **3**, "2" in (c) represents a state in which the second power source **31b** is selected. In FIG. **3**, (d) represents a temporal change of a driving pulse string (peak value) transmitted from one of the pulsers to the piezoelectric transducers of the ultrasonic probe **2**.

In FIG. **3**, V_0 , V_1 , V'_0 , and V_2 in (a), (b), and (d) respectively represent voltage values. In addition, T_0 to T_{10} in (c) in FIG. **3** respectively represent the times at which a power source is selected (the times at which a selected power source is switched) in the order named.

The sequence controller **23** exclusively selects a power source from which the ultrasonic diagnostic apparatus **1** transmits an applied voltage to a pulser in a push pulse period as a transmission mode. That is, the sequence controller **23** exclusively switches a power source to be selected.

For example, the sequence controller **23** selects the first power source **31a** at time T_0 (the start time of a push pulse period). The sequence controller **23** switches a power source to be selected from the first power source **31a** to the second power source **31b** at time T_1 (e.g., 150 μ s after time T_0). The sequence controller **23** switches a power source to be selected from the second power source **31b** to the first power source **31a** at time T_2 (e.g., 150 μ s after time T_1). The sequence controller **23** switches a power source to be selected from the first power source **31a** to the second power source **31b** at time T_3 (e.g., 150 μ s after time T_2). The sequence controller **23** switches a power source to be selected from the second power source **31b** to the first power source **31a** at time T_4 (e.g., 150 μ s after time T_3). The sequence controller **23** switches a power source to be selected from the first power source **31a** to the second power source **31b** at time T_5 (e.g., 150 μ s after time T_4). In this manner, in a push pulse period, the first power source **31a** or the second power source **31b** is exclusively selected. The ultrasonic probe **2** transmits a push pulse (a strong ultrasonic pulse for the generation of a shear wave from the interior of the object) in a push pulse period in response to a driving pulse string whose peak value is a maximum value V_0 transmitted from a pulser (the first pulser **211a** or the second pulser **211b**) corresponding to a power source to be selected (the first power source **31a** or the second power source **31b**). The ultrasonic probe **2** may transmit push pulses to, for

example, a plurality of portions in the object in a push pulse period (a push pulse transmission time at one portion is, for example, 900 μ s).

In the period from time T_5 to time T_6 , the first power source **31a** is inactive. The sequence controller executes control to change the open voltage of the inactive first power source **31a** from V_0 (e.g., 100 V) to V_1 (e.g., 130 V).

The sequence controller **23** switches a power source to be selected from the second power source **31b** to the first power source **31a** at time T_6 (the start time of a tracking period). The ultrasonic probe **2** transmits a tracking pulse (an ultrasonic pulse for the measurement of the propagation velocity of a shear wave generated from the interior of the object) in a tracking pulse transmission period (e.g., 700 μ s) in response to a driving pulse string whose peak value (its maximum value) is V_1 transmitted from the first pulser **211a**.

In the period from time T_6 to time T_7 , the second power source **31b** is inactive. The sequence controller executes control to change the open voltage of the inactive second power source **31b** from V_0 (e.g., 100 V) to V_2 (e.g., 150 V).

The sequence controller **23** switches a power source to be selected from the first power source **31a** to the second power source **31b** at time T_7 (the start time of a B-mode image generation period). The ultrasonic probe **2** transmits a B-mode pulse (an ultrasonic pulse for the generation of a B-mode image) in a B-mode image generation period (e.g., 500 μ s) in response to a driving pulse string whose peak value (its maximum value) is V_2 transmitted from the second pulser **211b**. In the period from time T_7 to time T_8 , the sequence controller **23** decides V'_0 as a voltage to be applied in a push pulse period in the next ultrasonic transmission/reception sequence based on an obtained shear wave analysis result or B-mode image. That is, the sequence controller **23** executes control to change the open voltage of the inactive first power source **31a** from V_1 (e.g., 130 V) to V'_0 (e.g., 80 V). Subsequently, in the period from time T_8 to time T_9 , the sequence controller **23** executes control to change the open voltage of the inactive second power source **31b** from V_2 (e.g., 150 V) to V'_0 (e.g., 80 V). The operation associated with the above sequence of an ultrasonic transmission/reception sequence (e.g., 1 sec) is executed a plurality of times.

It is possible to implement shear wave elastography of diagnosing hardness by using the ultrasonic diagnostic apparatus **1** according to the first embodiment described above. (First Modification)

In the ultrasonic diagnostic apparatus **1** according to the first embodiment described above, one pulse generation circuitry (e.g., the first pulse generation circuitry **210a**) is connected to one pulser (e.g., the first pulser **211a**). In the above case, however, since the sequence controller **23** exclusively selects a power source, a plurality of pulsers do not simultaneously output pulses. That is, as a modification, one pulse generation circuitry may be connected to each of a plurality of pulsers via a logic gate **212**.

FIG. 4 is an example of a block diagram of a transmission circuitry according to this modification of the first embodiment. The transmission circuitry **21** includes one pulse generation circuitry (a pulse generation circuitry **210**), pulsers (the first pulser **211a** and the second pulser **211b**), and the logic gates **212** corresponding to the respective pulsers. The logic gates **212** corresponding to the respective pulsers (the first pulser **211a** and the second pulser **211b**) are connected to the sequence controller **23**. The sequence controller **23** transmits the excitation pulse string generated by the pulse generation circuitry **210** to the pulser (e.g., the first pulser **211a**) corresponding to the selected power source

via the logic gate **212** based on the selected power source (e.g., the first power source **31a**). The first modification can also obtain the same effects as those obtained by the first embodiment.

(Second Modification)

In the ultrasonic diagnostic apparatus **1** according to the first embodiment including the first modification, one pulser (e.g., the first pulser **211a**) is connected to one power source (e.g., the first power source **31a**). This arrangement will be referred to as a single power source connected pulser. However, the number of pulsers may not correspond to the number of power sources in some case. For example, one pulser (e.g., the first pulser **211a**) may be connected to a plurality of power sources (e.g., the first power source **31a** and the second power source **31b**). This arrangement will be referred to as a multiple power source connected pulser. The ultrasonic diagnostic apparatus **1** may include one multiple power source connected pulser. Alternatively, the ultrasonic diagnostic apparatus **1** may include both a single power source connected pulser and a multiple power source connected pulser. In this case as well, the sequence controller **23** exclusively switches between the power sources. The second modification can also obtain the same effects as those described in the first embodiment.

(Third Modification)

The ultrasonic diagnostic apparatus **1** may include three or more power sources. The ultrasonic diagnostic apparatus **1** may include three or more pulsers. In this case as well, the sequence controller **23** exclusively switches between power sources. The third modification can also obtain the same effects as those obtained by the first embodiment which will be described later.

(Fourth Modification)

The ultrasonic diagnostic apparatus **1** exclusively switches between power sources. However, the technique of exclusively switching is merely an example and is not exhaustive. For example, a plurality of power sources (including some or all of the power sources) may be switched so as to be simultaneously used. For example, an overall applied voltage droop may be suppressed by lowering the voltage values of the respective power sources. Alternatively, while a plurality of power sources are simultaneously used, one power source may be selected as the main power source, and the remaining power sources may be used as auxiliary power sources. In such a case, the auxiliary power sources preferably apply voltages with lower voltage values than the voltage value of the main power source. In addition, exclusive switching and switching for simultaneous use may be performed within one sequence. The fourth modification can also obtain the same effects as those of the first embodiment which will be described later.

(Fifth Modification)

The power source unit **30** of the ultrasonic diagnostic apparatus **1** includes a plurality of power supplies. Therefore, some or all of the plurality of power sources in the power source unit **30** may be implemented by being replaced with capacitors or storage batteries typified by lead storage batteries, nickel cadmium batteries, and lithium ion batteries. That is, voltages may be applied to pulsers by using charge accumulated in the capacitors or power stored in the storage batteries. The fifth modification can also obtain the same effects as those obtained by the first embodiment which will be described later.

The ultrasonic diagnostic apparatus **1** according to the first embodiment can obtain the following effects.

As described above, for example, the sequence controller **23** exclusively selects a power source to apply a voltage to

a pulser by switching the electronic switch **32**. This shortens the period during which one power source is used, thereby reducing a droop in applied voltage. In addition, reducing the capacitance of a decoupling capacitor provided to reduce a droop can achieve downsizing of a power source. In addition, it is possible to transmit driving pulse strings with stable push pulse outputs to the ultrasonic probe **2** regardless of transmission conditions for push pulses output from the ultrasonic probe **2**. Therefore, the ultrasonic probe **2** may either a general one-dimensional array probe or a linear array probe which implements a wide field of view by connecting multiple arrays of piezoelectric transducers by switching them using a built-in high-pressure switch. Alternatively, the ultrasonic probe **2** may be a 1.25-dimensional probe or 1.5-dimensional probe which is designed to also divide piezoelectric transducers in the lens direction and connect them upon aperture switching.

As described above, a characteristic feature of this embodiment is that an inactive power source applies no voltage to a pulser. For this reason, the inactive power source can restore the applied voltage which has drooped at the time of an operation to the open voltage. That is, it is possible to reduce the influence of a droop in voltage at the time of the transmission of relatively strong ultrasonic waves such as push pulses.

The ultrasonic diagnostic apparatus **1** includes a plurality of power sources (e.g., two power sources). The plurality of power sources are exclusively selected. That is, the power value required for each of the plurality of power sources can be kept low. For this reason, it is possible to achieve downsizing and a reduction in cost of the circuitry constituted by power sources. In addition, the amount of heat generated is suppressed as compared that in related art, and hence cooling is facilitated.

As described above, the sequence controller **23** can execute control to change the value of the open voltage of an inactive power source. For this reason, the ultrasonic diagnostic apparatus **1** can implement shear wave measurement with higher sensitivity by changing the value of the open voltage of an inactive power source at the time of transition from a push pulse period to a tracking pulse period in, for example, shear wave elastography. Likewise, the ultrasonic diagnostic apparatus **1** can generate a B-mode image with higher sensitivity by changing the value of the open voltage of an inactive power source at the time of transition from a tracking pulse period to a B-mode pulse period in, for example, shear wave elastography.

(Comparison with Prior Art)

FIG. **5** is a block diagram representing an example of transmission circuitry in a conventional ultrasonic diagnostic apparatus. A conventional ultrasonic diagnostic apparatus **1** does not have the power source switching function of this embodiment. In addition, the conventional ultrasonic diagnostic apparatus **1** cannot change the value of the open voltage of an inactive power source.

FIG. **6** represents an example of timing charts representing a transmission pulse sequence in shear wave elastography using the conventional ultrasonic diagnostic apparatus. FIG. **6** represents four timing charts (a) to (d) in order from the top. In FIG. **6**, (a) represents a temporal change in the open voltage of a first power source **31a**. In FIG. **6**, (b) represents a temporal change in the open voltage of a second power source **31b**. In FIG. **6**, (c) represents a temporal change of a power source selected by a sequence controller **23**. That is, "1" in (c) in FIG. **6** represents a state in which the first power source **31a** is selected. In FIG. **6**, "2" in (c) represents a state in which the second power source **31b** is

selected. In FIG. **6**, (d) represents a temporal change of a driving pulse string (peak value) transmitted from one of the pulsers to the piezoelectric transducers of an ultrasonic probe **2**.

V_0 and V_1 in (a), (b), and (d) in FIG. **6** respectively correspond to V_0 and V_1 in (c) in FIG. **3**, and respectively indicate voltage values. In addition, T_0 and T_6 to T_8 in (c) in FIG. **6** respectively correspond to T_0 and T_6 to T_8 in (c) in FIG. **3**, and represent the times at which a power source is selected (the times at which a selected power source is switched).

The conventional ultrasonic diagnostic apparatus uses one power source (the first power source **31a** in this case) in a push pulse period. For this reason, the influence of a droop in applied voltage becomes noticeable (see the comparison between (d) in FIG. **3** and (d) in FIG. **6**). In addition, the capacitance of a decoupling capacitor provided to reduce a droop increases, resulting in an increase in the size of a power source. Furthermore, the amount of heat generated becomes larger than that in this embodiment. This makes it difficult to perform cooling.

In addition, since a conventional power source has a fixed open voltage, the conventional ultrasonic diagnostic apparatus **1** is lower in shear wave measurement sensitivity and B-mode image generation sensitivity than this embodiment (see the comparison between (a) and (b) in FIG. **3** and (a) and (b) in FIG. **6**).

(Second Embodiment)

In the first embodiment, the sequence controller **23** executes the power switching function at predetermined time intervals or in response to a predetermined pulse output count as a trigger (open loop control). On the other hand, in the second embodiment, a sequence controller **23** executes the power switching function under the feedback control using a comparator.

FIG. **7** is a block diagram representing an example of a transmission circuitry **21** according to the second embodiment. The same reference numerals denote the same constituent elements as those in the first embodiment, and a repetitive description will be omitted. In association with the transmission circuitry **21**, FIG. **7** also represents an ultrasonic probe **2**, a host computer **10**, the sequence controller **23**, and a power source unit **30** (power sources (a first power source **31a** and a second power source **31b**) and an electronic switch **32**). The transmission circuitry **21** includes a pulse generation circuitry **210**, pulsers (a first pulser **211a** and a second pulser **211b**), logic gates **212** corresponding to the respective pulsers, and comparators (a first comparator **213a** and a second comparator **213b**) corresponding to the respective power sources. In addition, an ultrasonic diagnostic apparatus **1** according to the second embodiment has the above power source switching function.

The first comparator **213a** compares the applied voltage transmitted from the first power source **31a** to the first pulser **211a** and the first constant voltage (the monitoring voltage of the first power source) output from the host computer **10** (monitoring means). For example, the monitoring voltage of the first power source may be set to, for example, 90% of the open voltage of the first power source **31a**, as a threshold. The first comparator **213a** transmits two different voltage values (i.e., 1-bit computation representing 0 or 1) to the sequence controller **23** based on the comparison result. When, for example, the sequence controller **23** has selected the first power source **31a**, the sequence controller **23** selects the second power source **31b** via the electronic switch **32** in response to a moment when the applied voltage becomes lower than the threshold, i.e., the voltage value representing

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0 switches to the voltage value representing 1 (or the voltage value representing 1 switches to the voltage value representing 0) as a trigger.

Likewise, a second comparator **213b** compares the applied voltage transmitted from the second power source **31b** to the second pulser **211b** and the second constant voltage (the monitoring voltage of the second power source) output from the host computer **10**. For example, the monitoring voltage of the second power source may be set to, for example, 90% of the open voltage of the second power source **31b**, as a threshold. The second comparator **213b** transmits two different voltage values (i.e., 1-bit computation representing 0 or 1) to the sequence controller **23** based on the comparison result. When, for example, the sequence controller **23** has selected the second power source **31b**, the sequence controller **23** selects the first power source **31a** via the electronic switch **32** in response to a moment when the applied voltage becomes lower than the threshold, i.e., the voltage value representing 0 switches to the voltage value representing 1 (or the voltage value representing 1 switches to the voltage value representing 0) as a trigger.

The ultrasonic diagnostic apparatus **1** according to the second embodiment can obtain the following effects.

As described above, for example, the sequence controller **23** exclusively selects a power source to apply a voltage to a pulser by switching the electronic switch **32**. This shortens the period during which one power source is used, and can reduce a droop in applied voltage. In addition, reducing the capacitance of a decoupling capacitor provided to reduce a droop can achieve downsizing of the power source. In addition, it is possible to transmit a stable driving pulse string for stabilizing a push pulse output regardless of the transmission conditions for the push pulse output from the ultrasonic probe **2**. Therefore, the ultrasonic probe **2** may either a general one-dimensional array probe or a linear array probe which implements a wide field of view by connecting multiple arrays of piezoelectric transducers by switching them using a built-in high-pressure switch. Alternatively, the ultrasonic probe **2** may be a 1.25-dimensional probe or 1.5-dimensional probe which is designed to also divide piezoelectric transducers in the lens direction and connect them upon aperture switching.

As described above, a characteristic feature of this embodiment is that an inactive power source applies no voltage to a pulser. For this reason, the inactive power source can restore the applied voltage which has drooped at the time of an operation to the open voltage. That is, it is possible to reduce the influence of a droop in voltage at the time of the transmission of relatively strong ultrasonic waves such as push pulses.

The ultrasonic diagnostic apparatus **1** includes a plurality of power sources (e.g., two power sources). The plurality of power sources are exclusively selected. That is, the power value required for each of the plurality of power sources can be kept low. For this reason, it is possible to achieve downsizing and a reduction in cost of the circuitry constituted by power sources. In addition, the amount of heat generated is suppressed as compared with that in related art, and hence cooling is facilitated.

As described above, the sequence controller **23** can execute control to change the value of the open voltage of an inactive power source. For this reason, the ultrasonic diagnostic apparatus **1** can implement shear wave measurement with higher sensitivity by changing the value of the open voltage of an inactive power source at the time of transition from a push pulse period to a tracking pulse period in, for example, shear wave elastography. Likewise, the ultrasonic

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diagnostic apparatus **1** can generate a B-mode image with higher sensitivity by changing the value of the open voltage of an inactive power source at the time of transition from a tracking pulse period to a B-mode pulse period in, for example, shear wave elastography.

Note that a plurality of units or apparatuses according to the present embodiment may be implemented by processors or processing circuitry. The processing circuitry may be constituted of a singular set of circuitry such as a CPU, plural sets of circuitry corresponding to each of the units, or the combination thereof.

Furthermore, the word “processor” or “processing circuitry” used in the above description means circuitry such as a CPU (Central Processing Unit), a GPU (Graphics Processing Unit), an ASIC (Application Specific Integrated Circuit), a programmable logic device (e.g., an SPLD (Simple Programmable Logic Device), a CPLD (Complex Programmable Logic Device), or an FPGA (Field Programmable Gate Array)), or the like. The processor implements functions by reading out programs stored in the storage circuit and executing the programs. Note that it is possible to directly incorporate programs in the circuit of the processor instead of storing the programs in the storage circuit. In this case, the processor implements functions by reading out programs incorporated in the circuit and executing the programs.

Note that each processor in each embodiment described above may be formed as one processor by combining a plurality of independent circuits to implement functions as well as being formed as a single circuit for each processor. In addition, a plurality of constituent elements in each embodiment described above may be integrated into one processor to implement its function.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel methods and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

The invention claimed is:

1. An ultrasonic diagnostic apparatus, comprising:

an ultrasonic probe including a plurality of piezoelectric transducers, and configured to generate ultrasonic waves in response to supplied driving pulse signals;

at least one pulser configured to output a driving pulse signal to at least one of the plurality of piezoelectric transducers;

a plurality of power supplies implemented by circuitry and associated with the at least one pulser to apply voltages to the at least one pulser for generation of the driving pulse signal; and

a controller implemented by circuitry, configured to alternately select, at predetermined timing, application of the voltages from the plurality of power supplies in a push pulse transmission period in shear wave elastography during which push pulses are transmitted by the ultrasonic probe so as to prevent voltage droop in the voltages applied to the at least one pulser, wherein one of more power supplies of the plurality of power supplies that are not selected for the application of the voltages apply no voltage to the at least one pulser.

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2. An ultrasonic diagnostic apparatus, comprising:
 an ultrasonic probe including a plurality of piezoelectric
 transducers, and configured to generate ultrasonic
 waves in response to supplied driving pulse signals;
 at least one pulser configured to output a driving pulse
 signal to at least one of the plurality of piezoelectric
 transducers;
 a plurality of power supplies implemented by circuitry
 and associated with the at least one pulser to apply
 voltages to the at least one pulser for generation of the
 driving pulse signal; and
 a controller implemented by circuitry, configured to alter-
 nately select, at predetermined timing, application of
 the voltages from the plurality of power supplies in an
 ultrasonic transmission period during drug delivery to
 control an internal distribution of a drug in an object by
 using breakage of a capsule of the drug with ultrasonic
 waves from the ultrasonic probe so as to prevent
 voltage droop in the voltages applied to the at least one
 pulser,
 one of more power supplies of the plurality of power
 supplies that are not selected for the application of the
 voltages apply no voltage to the at least one pulser.
3. The apparatus according to the claim 1, wherein the
 controller is further configured to alternately select applica-
 tion of the voltages from the power supplies at predeter-
 mined time intervals.
4. The apparatus according to the claim 1, wherein the
 controller is further configured to alternately select applica-
 tion of the voltages from the power supplies for each of
 predetermined pulse output counts.
5. The apparatus according to the claim 1, further com-
 prising a monitoring unit implemented by circuitry, config-
 ured to monitor the applied voltage,

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- wherein the controller is further configured to alternately
 select application of the voltages from the power sup-
 plies every time the applied voltage becomes lower
 than a predetermined threshold.
6. The apparatus according to the claim 1, wherein the
 controller is further configured to change an open voltage of
 an inactive power supply.
7. The apparatus according to the claim 1, wherein the
 plurality of power supplies each comprise at least one of a
 power source, a storage battery, and a capacitor.
8. The apparatus according to the claim 2, wherein the
 controller is further configured to alternately select applica-
 tion of the voltages from the power supplies at predeter-
 mined time intervals.
9. The apparatus according to the claim 2, wherein the
 controller is further configured to alternately select applica-
 tion of the voltages from the power supplies for each of
 predetermined pulse output counts.
10. The apparatus according to the claim 2, further
 comprising a monitoring unit implemented by circuitry,
 configured to monitor the applied voltage,
 wherein the controller is further configured to alternately
 select application of the voltages from the power sup-
 plies every time the applied voltage becomes lower
 than a predetermined threshold.
11. The apparatus according to the claim 2, wherein the
 controller is further configured to change an open voltage of
 an inactive power supply.
12. The apparatus according to the claim 2, wherein the
 plurality of power supplies each comprise at least one of a
 power source, a storage battery, and a capacitor.

* * * * *

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摘要(译)

通常，根据一个实施例，超声诊断设备包括超声探头，由电路实现的多个电源，至少一个脉冲发生器，以及由电路实现的控制器。超声波探头包括多个压电换能器，其响应于所提供的驱动信号而产生超声波。脉冲发生器基于从多个电源中的任何一个施加的施加电压输出驱动信号。控制器根据用于在一个传输模式时段中产生驱动信号的至少一个脉冲发生器来切换多个电源。

