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(54) **PORTABLE ULTRASONIC IMAGING PROBE INCLUDING TRANSDUCER ARRAY**

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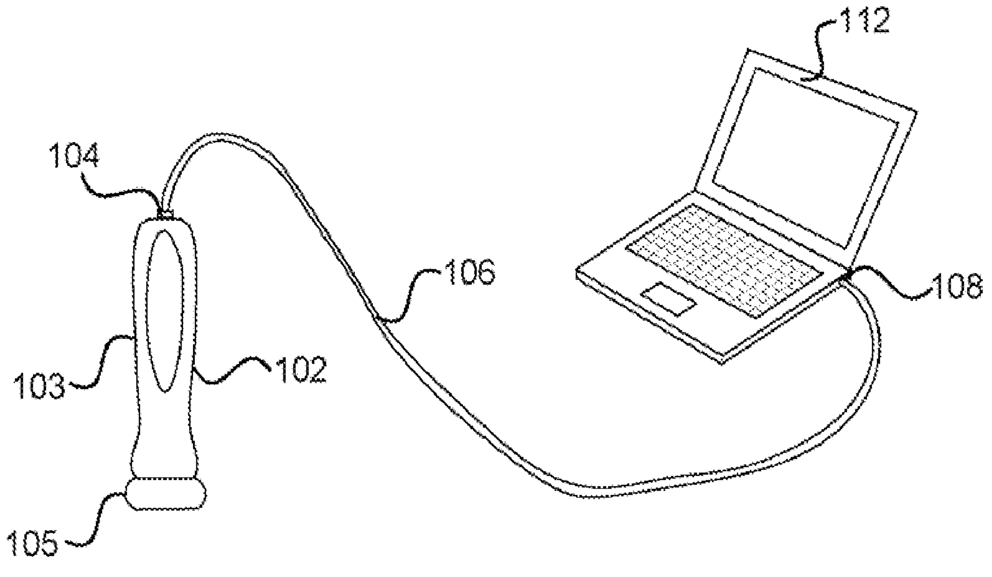
USPC **600/447**

(57) **ABSTRACT**

The invention provides a portable ultrasonic imaging probe directly connectable to an off-the-shelf laptop computer. The probe produces raw digitized data comprising envelope detected ultrasound echo data from an array of ultrasound transducers, and transmits the data to the host computer thereby enabling the host computer to form real-time ultrasonic images of human tissue without the need for any additional electronics. In particular embodiments, the probe includes a plurality of transmit switches configured to connect a transmitting group of the ultrasound transducers to a pulser; a plurality of receive switches configured to connect a receiving group of the ultrasound transducers to analog summing, amplification and signal processing circuitry; and a transmit/receive controller which selects which of said ultrasound transducers are in the transmitting group and which of said ultrasound transducers are in the receiving group. The ultrasound transducers may be conventional or micromachined ultrasound transducers.



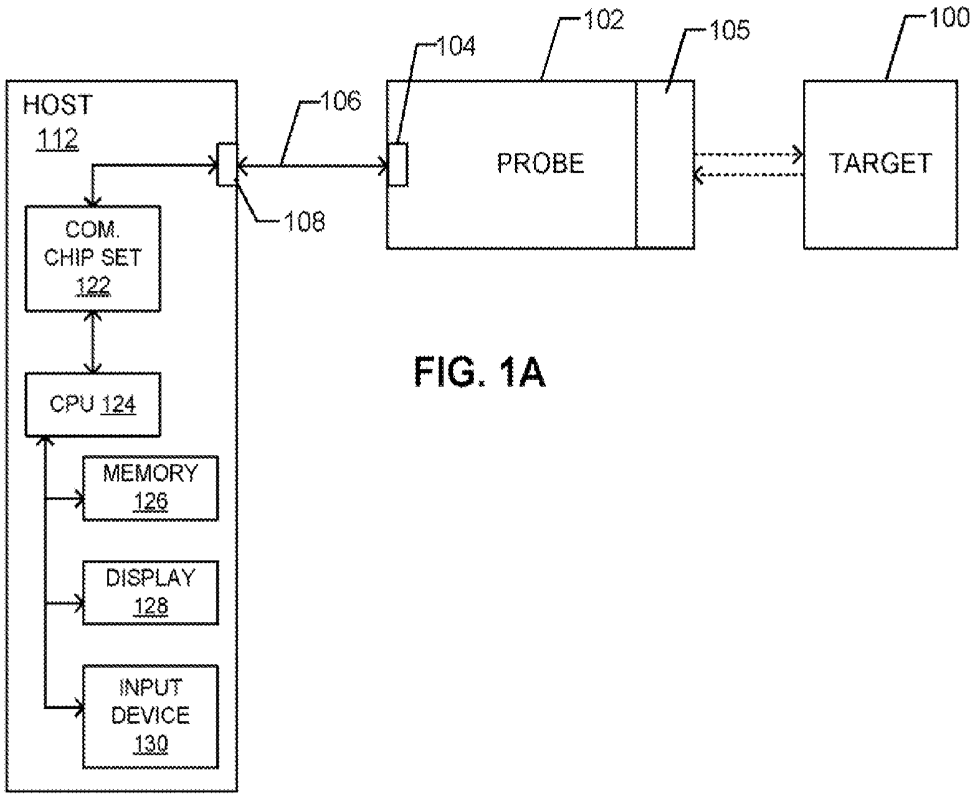

HOST
112
COM.
CHIP SET
122
CPU 124
MEMORY
126
DISPLAY
128
INPUT
DEVICE
130
108
106
104
102
PROBE
105
100
TARGET

FIG. 1A

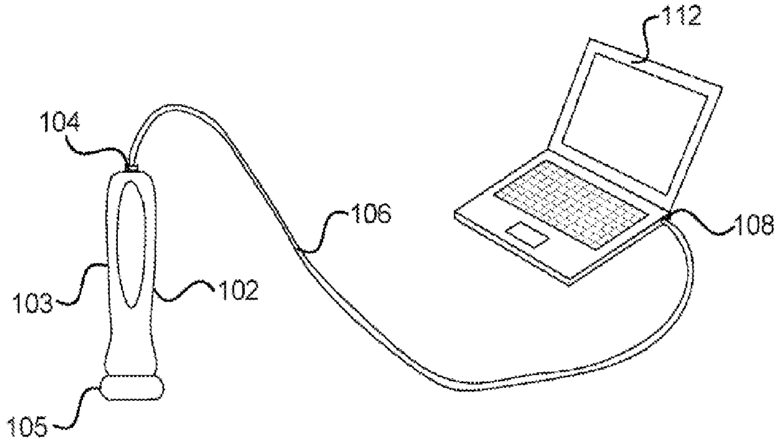

112
104
106
108
103
102
105

FIG. 1B

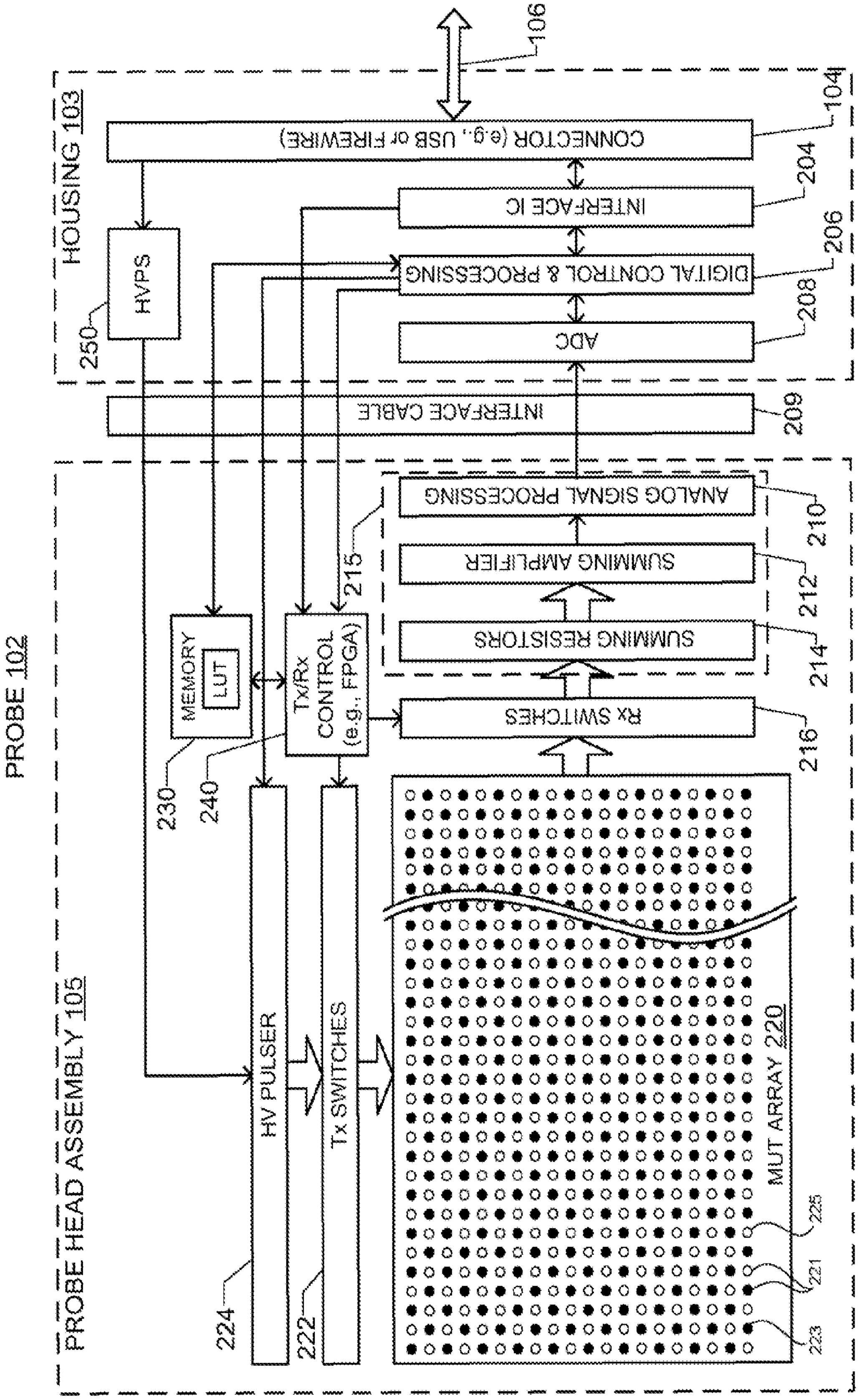

106
HOUSING 103
104
CONNECTOR (e.g., USB or FIREWIRE)
204
INTERFACE IC
206
DIGITAL CONTROL & PROCESSING
208
ADC
250
HVPS
209
INTERFACE CABLE
PROBE 102
PROBE HEAD ASSEMBLY 105
215
ANALOG SIGNAL PROCESSING
210
SUMMING AMPLIFIER
212
SUMMING RESISTORS
214
RX SWITCHES
216
MEMORY
LUT
230
Tx/Rx CONTROL (e.g., FPGA)
240
HV PULSER
224
Tx SWITCHES
222
MUT ARRAY 220
225
221
223

FIG. 2A

FIG. 2B

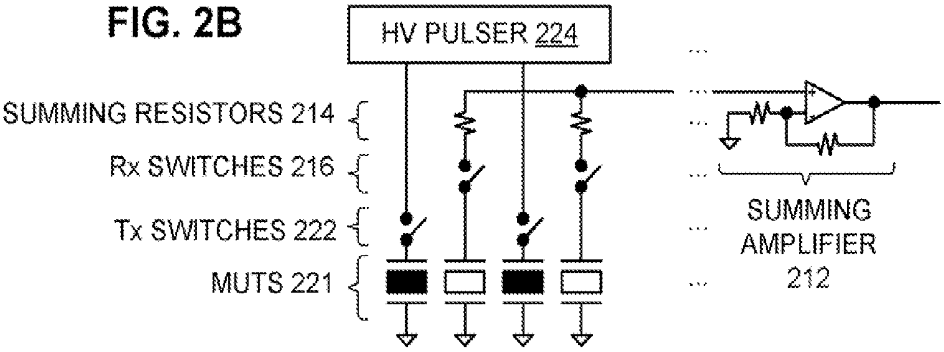


FIG. 2C

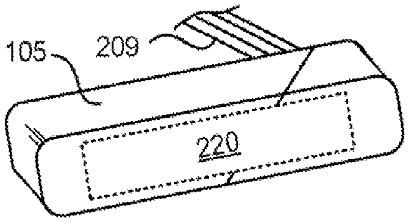


FIG. 2D

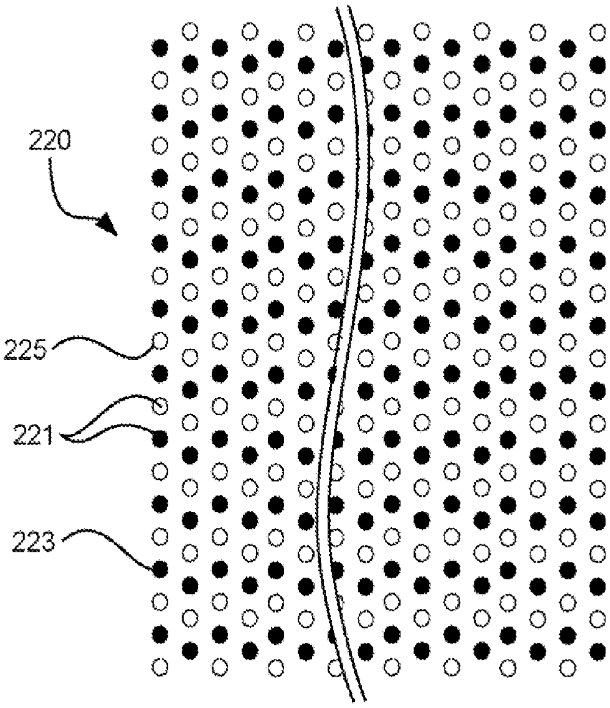
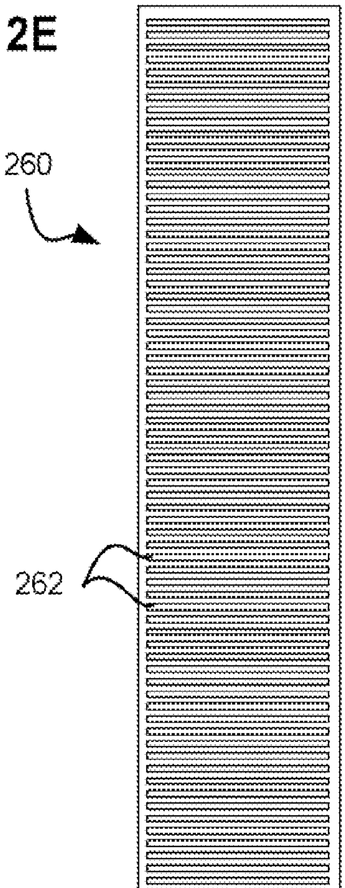


FIG. 2E



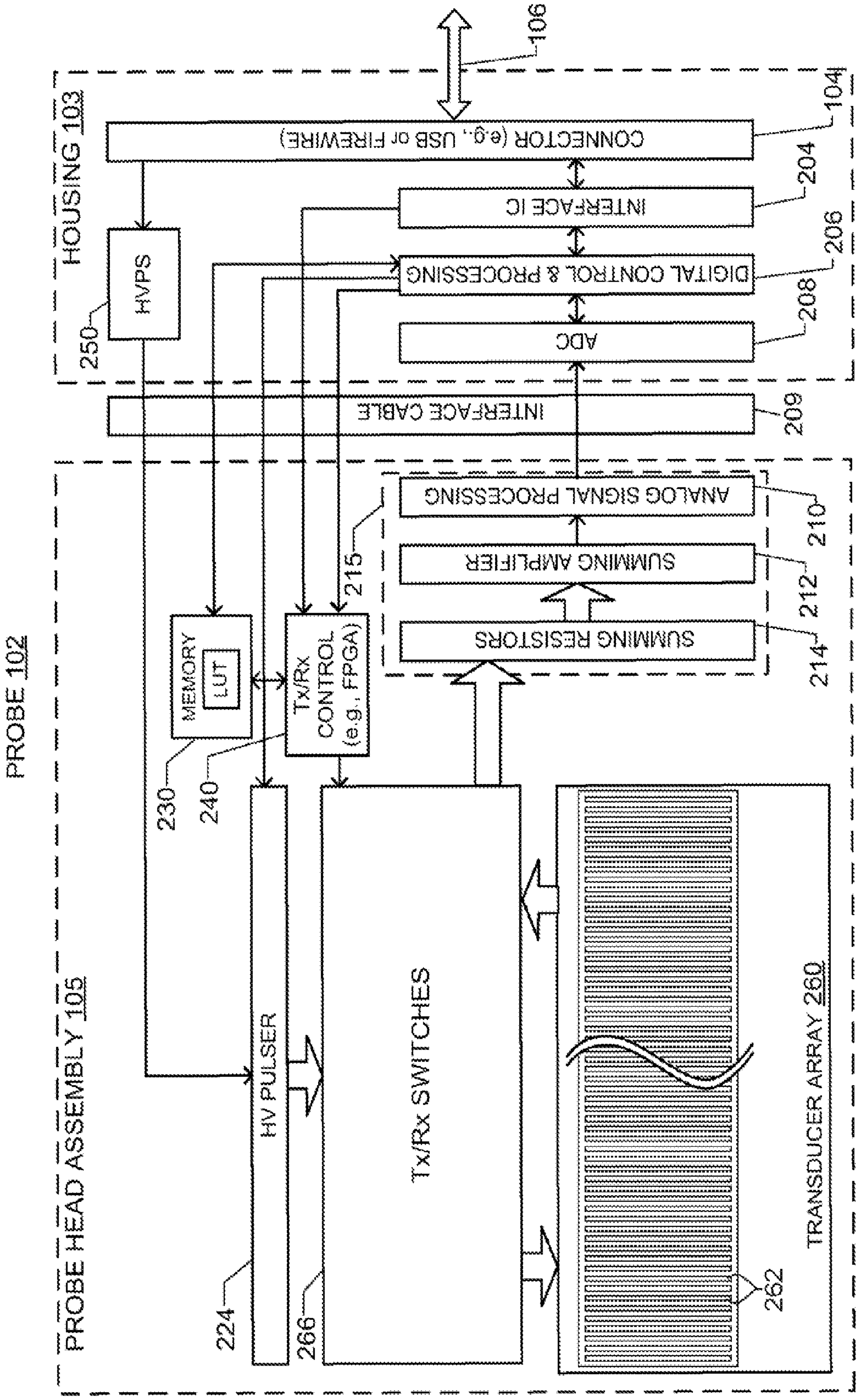
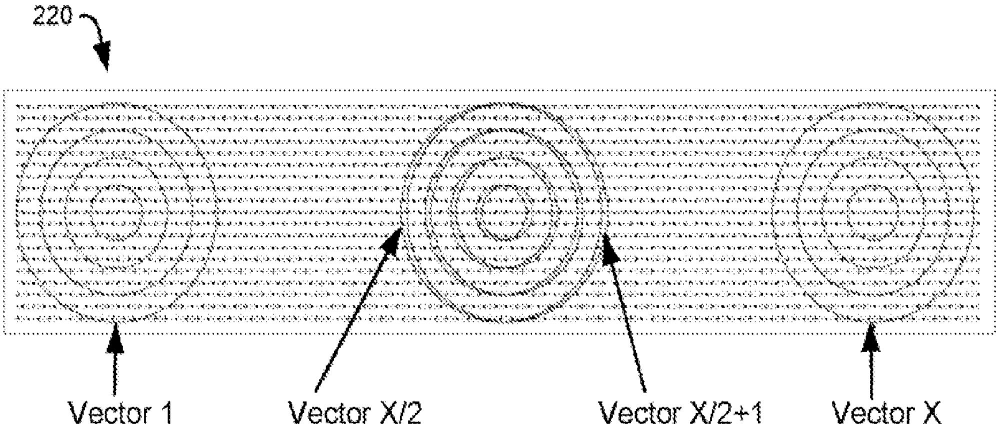

106
HOUSING 103
104
CONNECTOR (e.g., USB or FIREWIRE)
204
INTERFACE IC
206
DIGITAL CONTROL & PROCESSING
208
ADC
250
HVPS
INTERFACE CABLE
209
PROBE 102
PROBE HEAD ASSEMBLY 105
ANALOG SIGNAL PROCESSING
210
SUMMING AMPLIFIER
212
SUMMING RESISTORS
214
215
MEMORY
LUT
230
Tx/Rx CONTROL (e.g., FPGA)
240
HV PULSER
224
Tx/Rx SWITCHES
266
TRANSDUCER ARRAY 260
262

FIG. 2F

FIG. 3A



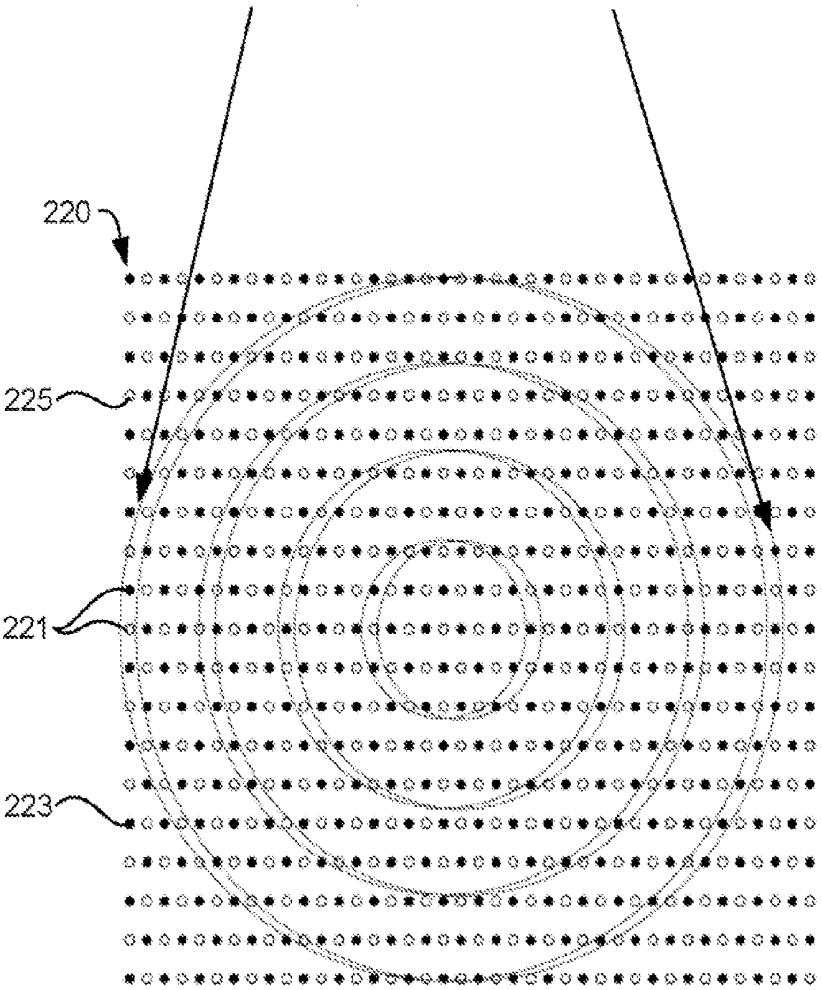


FIG. 3B

FIG. 3C

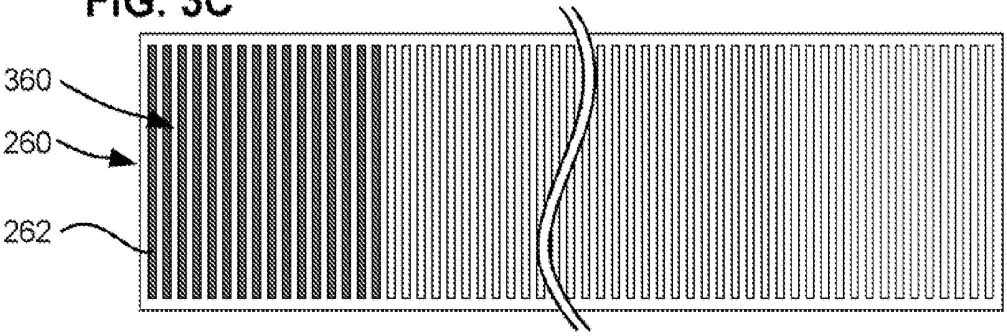


FIG. 3D

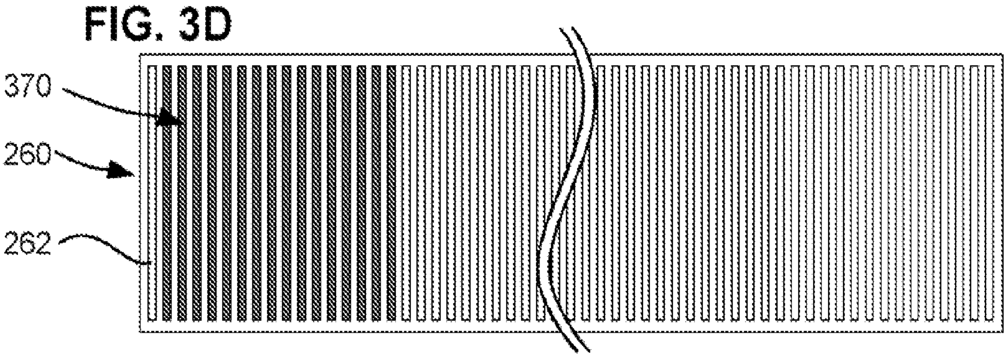


FIG. 3E

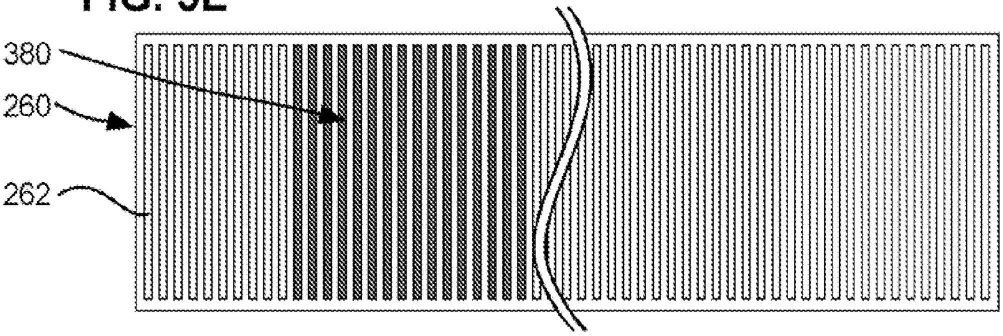


FIG. 3F

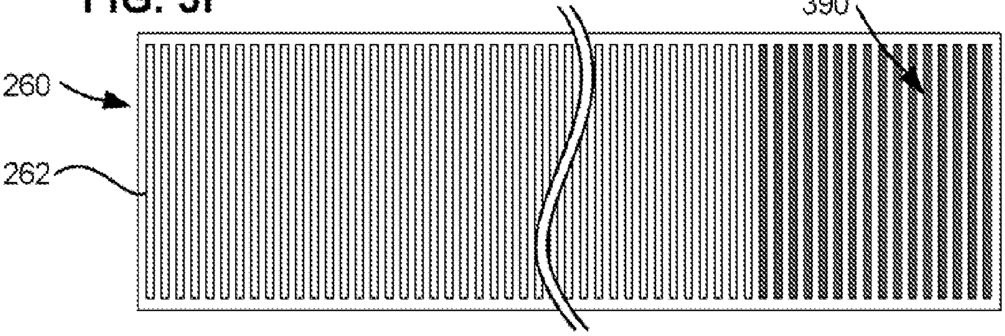
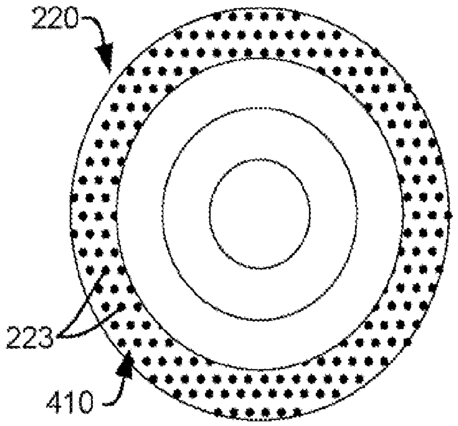
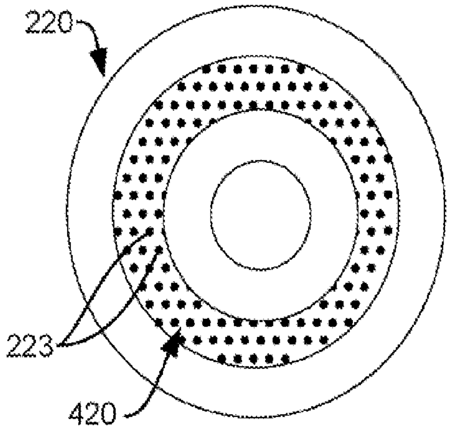


FIG. 4A



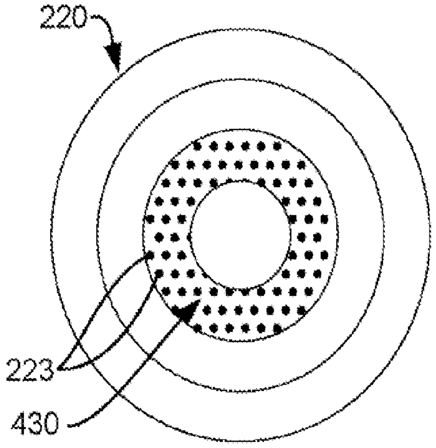
(a) Transmit 1

FIG. 4B



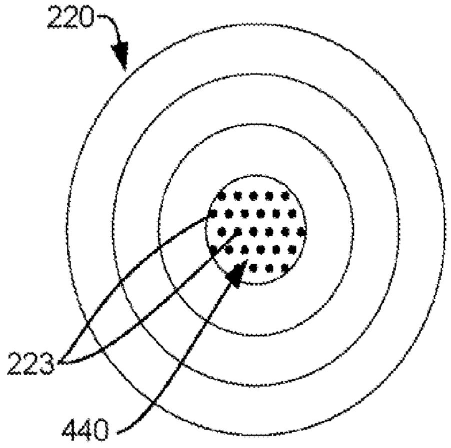
(b) Transmit 2

FIG. 4C



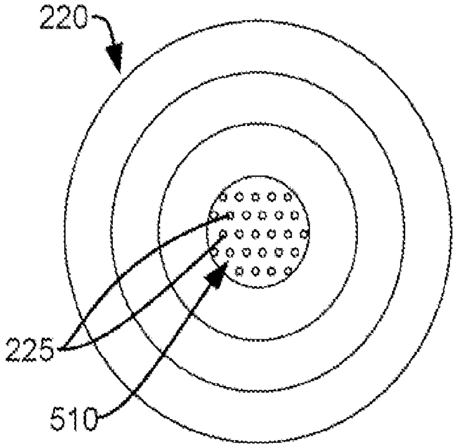
(c) Transmit 3

FIG. 4D



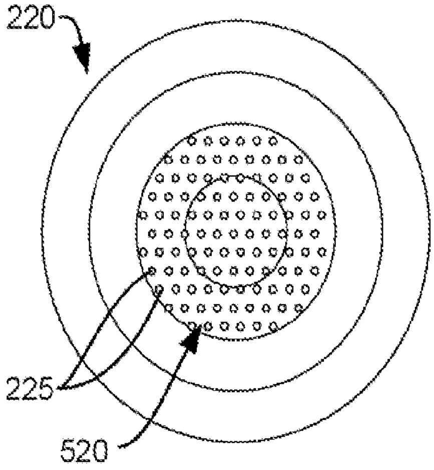
(d) Transmit 4

FIG. 5A



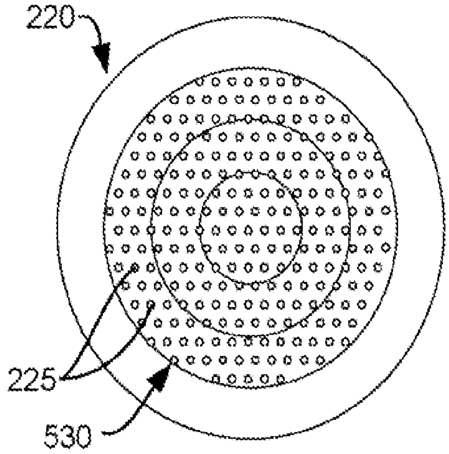
(a) Receive 1

FIG. 5B



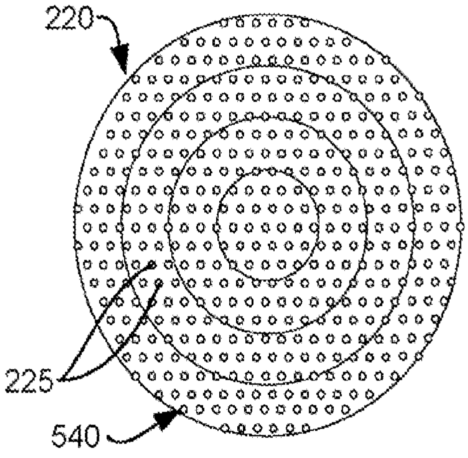
(b) Receive 2

FIG. 5C



(c) Receive 3

FIG. 5D



(d) Receive 4

FIG. 6A

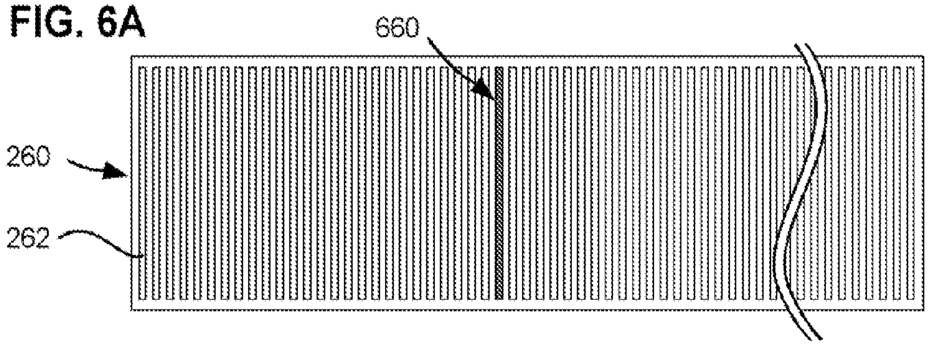


FIG. 6B

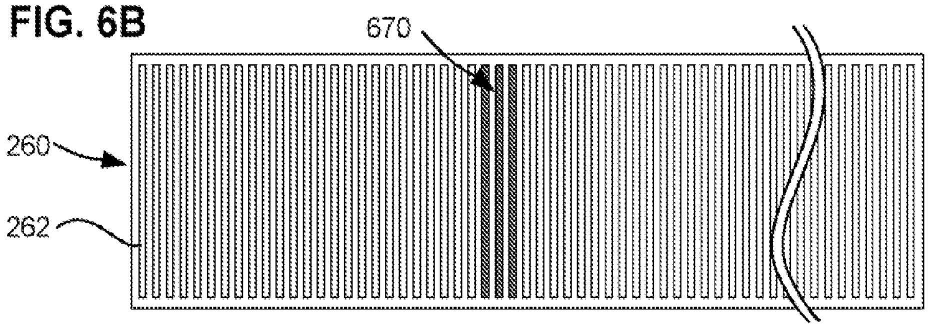


FIG. 6C

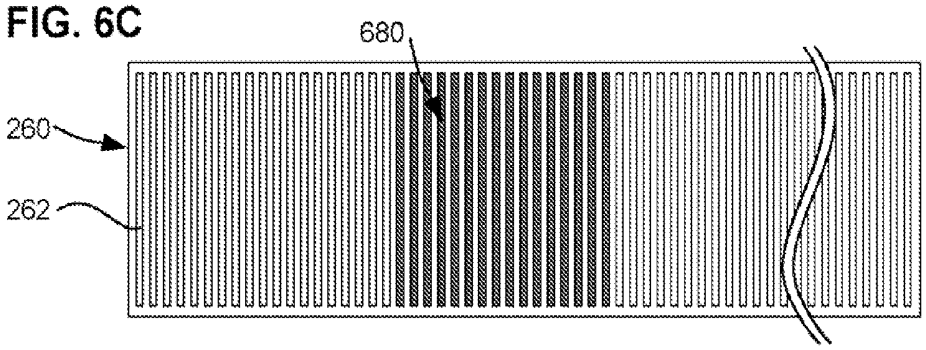
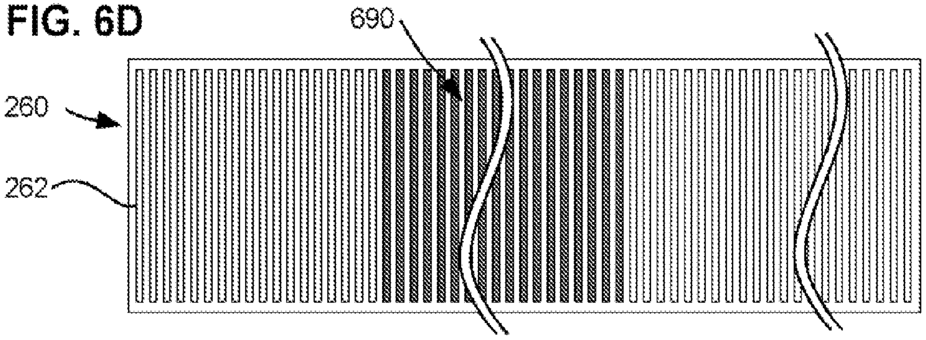


FIG. 6D



PORTABLE ULTRASONIC IMAGING PROBE INCLUDING TRANSDUCER ARRAY

PRIORITY CLAIM

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application No. 61/676,193 filed Jul. 26, 2012 entitled "PORTABLE ULTRASOUND IMAGING PROBE INCLUDING MEMS BASED TRANSDUCER ARRAY" which application is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to portable ultrasonic imaging probes, and more specifically, to such probes including a transducer array, wherein such probes can be directly connected to a host computer, such as an off-the-shelf laptop computer, or the like.

BACKGROUND

[0003] Typically, ultrasound imaging systems include a hand-held probe that is connected by a cable to a relatively large and expensive piece of hardware that is dedicated to performing ultrasound signal processing and displaying ultrasound images. Such systems, because of their high cost, are typically only available in hospitals or in the offices of specialists, such as radiologists. Recently, there has been an interest in developing more portable ultrasound imaging systems that can be used with personal computers. Preferably, such a portable ultrasound probe can be used with an off-the-shelf host computer, such as a personal computer, and is inexpensive enough to provide ultrasound imaging capabilities to general practitioners and health clinics having limited financial resources.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1**A is a high level diagram showing elements of the present invention.

[0005] FIG. **1**B illustrates an ultrasonic imaging probe according to an embodiment of the present invention originally described with reference to FIG. **1**A.

[0006] FIG. **2**A is a block diagram that shows additional details of an ultrasonic imaging probe according to an embodiment of the present invention.

[0007] FIG. **2**B illustrates some further details of some of the blocks introduced in FIG. **2**A, according to an embodiment of the present invention.

[0008] FIG. **2**C illustrates a perspective view of a probe head assembly, according to an embodiment of the present invention.

[0009] FIG. **2**D illustrates how odd and even rows of transducers can be staggered relative to one another according to an embodiment of the present invention.

[0010] FIG. **2**E illustrates an alternative array of ultrasound transducers according to an embodiment of the present invention.

[0011] FIG. **2**F is a block diagram that shows details of an alternative ultrasonic imaging probe according to an embodiment of the present invention.

[0012] FIG. **3**A shows how sets of micromachined ultrasound transducers can be used to form a moving quasi-annular array transducer according to an embodiment of the present invention.

[0013] FIG. **3**B is a blown-up view of two of the vectors shown in FIG. **3**A.

[0014] FIGS. **3**C-**3**F show how sets of ultrasound transducers can be used to form a moving square array transducer according to an embodiment of the present invention.

[0015] FIGS. **4**A-**4**D illustrate a transmit sequence, according to an embodiment of the present invention.

[0016] FIGS. **5**A-**5**D illustrate a receive sequence, according to an embodiment of the present invention.

[0017] FIGS. **6**A-**6**D illustrate a receive sequence, according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0018] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific illustrative embodiments. It is to be understood that other embodiments may be utilized and that mechanical and electrical changes may be made. The following detailed description is, therefore, not to be taken in a limiting sense. In the description that follows, like numerals or reference designators will be used to refer to like parts or elements throughout. In addition, the first digit of a reference number identifies the drawing in which the reference number first appears.

[0019] FIG. **1**A shows an ultrasonic imaging probe **102**, according to an embodiment of the present invention, which is connected by a passive interface cable **106** to a host computer **112**. Ultrasonic imaging probe **102** includes an array of ultrasound transducers for transmitting and receiving ultrasound pulses as will be described below. The host computer **112** can be a desktop personal computer (PC), a laptop PC, a pocket PC, a tablet PC, a mobile phone capable or running software programs (often referred to as a "smart phone"), a personal digital assistant, or the like. The passive interface cable **106**, which includes connectors and passive wires, can be a Universal Serial Bus (USB) cable (e.g., a USB 2.0 cable), a FireWire (also known as IEEE 1394) cable, or the like. Preferably the probe **102** is not connected to any other device or power supply. Thus, in a preferred embodiment the probe **102** receives all its necessary power from the host computer **112** via the passive interface cable **106**. In alternative embodiments, probe **102** can include a battery and a wireless transceiver, in which case the probe can wireless communicate with the host computer, and the probe can generate all its necessary power from the battery.

[0020] As will be described in more detail below, in accordance with embodiments of the present invention, the probe **102** enables the host computer **112**, via software running on the host computer **112**, to form real-time ultrasonic images of a target **100** (e.g., human tissue or other materials) without the need for any additional internal or external electronics, power supply, or support devices. In certain embodiments, the probe **102** produces raw digitized data that is envelope detected ultrasound echo data from an array of ultrasound transducers in the probe **102**, and transmits such raw data to the host computer **112**. The raw digitized data can optionally also be logarithmically compressed, depending upon implementation.

[0021] In an embodiment, when the host computer **112** receives raw data via the passive interface cable **106** from the probe **102**, the host computer **112** performs time gain compensation (TGC), gray-scale mapping, and scan conversion of the raw data using software that runs on the host computer **112**, and displays the resultant video images. The probe does not include any moving mechanical parts, thereby reducing the complexity and cost of the probe **102** and increasing its reliability. The term "raw data", as used herein, refers to ultrasound imaging data that has not yet been time gain compensated, gray-scale mapped and scan converted. As described below, such raw data is included in the digital signal that is transferred from the probe **102** to the host computer **112**.

[0022] As shown in FIG. **1**A, the host computer **112** will likely include a communications port **108**, a communications chip-set **122**, a central processing unit (CPU) **124**, memory **126**, a display **128**, and an input device **130**, such as a keyboard, mouse, touch screen, track ball, or the like. Additionally, the host computer **112** runs software that enables the host to control specific aspects of the probe **102**. Such software also enables the host computer **112** to perform time gain compensation (also known as time gain correction), gray-scale mapping, and scan conversion of the raw data received from the probe **112** over the passive interface cable **106**. The host computer **112** can then display the resulting ultrasound video on the display **128**, as well as store such video in its memory **126**, or another data storage device (not shown).

[0023] The article "A New Time-Gain Correction Method for Standard B-Mode Ultrasound Imaging", by William D. Richard, *IEEE Transactions of Medical Imaging*, Vol. 8, No. 3, pp. 283-285, September 1989, which is incorporated herein by reference, describes an exemplary time gain correction technique that can be performed by the host computer **112**. The article "Real-Time Ultrasonic Scan Conversation via Linear Interpolation of Oversampled Vectors," *Ultrasonic Imaging*, Vol. 16, pp. 109-123, April 1994, which is incorporated herein by reference, describes an exemplary scan conversion technique that can be performed by the host computer **112**. These are just exemplary details of the host computer **112**, which are not meant to be limiting.

[0024] The passive interface cable **106** includes at least one data line over which data is carried, and at least one power line to provide power to a peripheral device, which in this case is the ultrasonic imaging probe **102**. For example, where the passive interface cable **106** is a USB 2.0 cable, one wire of the cable provides about 5V at about ½ Amp. In alternative embodiments, the passive interface cable **106** is a Firewire cable, which also includes a power wire. Other types of passive interface cable can be used if desired. However, as mentioned above, it is preferred that the passive interface cable **106** is a standard off-the-shelf cable that can interface with an off-the-shelf interface IC. The term passive as used herein refers to a cable that does not regenerate signals or process them in any way. In an alternative embodiment, the probe **102** and the host computer **112** communicate wirelessly, and the probe **102** includes a battery that is used to power the components within the probe.

[0025] FIG. **1**B illustrates an example where the host computer **112** is a laptop. FIG. **1**B also shows an exemplary ergonomic design of a housing **103** for the ultrasonic imaging probe **102** of the present invention. Other ergonomic designs are of course possible, and within the scope of the present invention. Also, as explained above, other types of host computer **112** can also be used. FIG. **1**B also shows that the ultrasonic imaging probe **102** includes a probe head assembly **105**.

[0026] In accordance with certain embodiments, the data samples produced by the ultrasound imaging probe **102** of the present invention are transmitted by the probe **102** across the interface cable **106** to the host computer **112**. In a specific embodiment, this is accomplished when the host computer **112** reads the data temporarily stored in the buffers of the interface IC **204**. The host computer **112** runs software that enables the host to perform time gain compensation (TGC), gray-scale mapping, and scan conversion of the data received from the probe **102**. The host computer generates and displays the resultant ultrasound video images. Advantageously, the host computer **112** does not need to perform electronic beamforming or other equivalent image processing, thereby simplifying the software that the host computer **112** runs.

[0027] The host computer **112** can use the digital data received from the ultrasound device **102** to provide any available type of ultrasound imaging mode can be used by the host computer **112** to display the ultrasound images, including, but not limited to A-mode, B-mode, M-mode, etc. For example, in B-mode, the host computer **112** performs know scan conversion such that the brightness of a pixel is based on the intensity of the echo return.

[0028] A benefit of specific embodiments of the present invention is that only digital signals are transmitted from the probe **102** to the host computer **112**, thereby providing for better signal-to-noise ratio than if analog signals were transmitted from the probe **102** to the host computer **112**, or to some intermediate apparatus between the host computer and the probe. Another benefit of specific embodiments of the present invention is that the probe **102** can be used with a standard off-the-shelf passive interface cable.

[0029] A further benefit of specific embodiments of the present invention is that the probe **102** does not perform any time gain compensation, gray-scale mapping and scan conversion, thereby significantly decreasing the complexity, power requirements and cost of the probe **102**. Conventionally, functions such as scan conversion, time gain correction (also known as time gain compensation) and gray-scale mapping are performed by a machine that is dedicated to obtaining ultrasound images, or by an intermediate device that is located between the probe and host computer. In contrast, in embodiments of the present invention, software running on the host computer **112** is used to perform these functions, thereby reducing the complexity and cost of the portable ultrasonic imaging probe **102**.

[0030] FIG. **2**A is a block diagram that shows additional details of an ultrasonic imaging probe according to an embodiment of the present invention. Additional details of the ultrasonic imaging probe **102**, according to specific embodiments of the present invention, shall now be described with reference FIG. **2**A. As shown in FIG. **2**A, in accordance with an embodiment of the present invention, the probe **102** includes a peripheral connector **104** and an interface IC **204** that enables the probe **102** to interface with the host computer **112** via the interface cable **106**. The connector **104** and the interface IC **204** are preferably off-the-shelf devices, but can be custom devices.

[0031] In accordance with an embodiment illustrated in FIG. **2**A, specific certain components (shown within a large dash-lined rectangle) are located within the probe head assembly **105**, with the remaining components being within the housing **103** of the ultrasonic imaging probe **102**. An interface cable **209** connects the components within the housing **103** to the components within the probe head assembly **105**.

[0032] The probe **102** is also shown as including a digital control and processing block **206**, an analog to digital converter (ADC) **208** and a high voltage power supply (HVPS) **250**. The HVPS **250** provides power to a high voltage (HV) pulser **224**. Additionally, the probe **102** is shown as including a micromachined ultrasound transducer (MUT) array **220**, which includes individually controllable MUT elements **221**, which are discussed in additional detail below. A transmit and receive (Tx/Rx) controller **240** accesses vector configuration and timing data stored within a memory **230** in order to controls transmit (Tx) switches **222** and receive (Rx) switches **216**, to thereby control the operation of the MUT elements **221** of the MUT array **220**, as described in additional detail below. In certain embodiments, such vector configuration and timing data is stored within a look-up table (LUT) within the memory **230**.

[0033] The probe **102** also includes analog summing, amplification and processing circuitry **215**. In accordance with an embodiment, the analog summing, amplification and processing circuitry **215** includes summing resistors **214** and a summing amplifier **212**, which are discussed in more detail with reference to FIG. 2B, and an analog signal processing block **210**. The analog signal processing block **210** can include, e.g., a pre-amplifier, a filter (e.g., a low pass or bandpass filter) and an envelope detector, and optionally a logarithmic amplifier. Such a pre-amplifier can be, e.g., a very low noise amplifier that provides about 20 dB of gain. The filter can filter out frequencies that are not of interest. The summing resistors **214** and the summing amplifier **212** combine numerous echo signals (received using numerous MUT elements) into a single echo signal. In accordance with an embodiment, this single echo signal is pre-amplified, filtered (e.g., low pass filtered) and envelope detected to produce a radio frequency (RF) signal. Logarithmic compression can be performed within the analog signal processing block **210**, or within the digital control and processing block **210**, or alternatively, within the host computer **112**.

[0034] The RF signal output by the analog signal processing block **210** is digitized by the ADC **208**. The ADC **208** samples the RF signal (e.g., at 30 or 48 MHz), to thereby digitize the signal, and provides the digitized signal to the digital control and processing block **210**. The digital control and processing block **206** could be implemented, e.g., using a complex programmable logic device (CPLD), a field-programmable gate array (FPGA), an application specific integrated circuit (ASIC) or some other circuitry. The digital control and processing clock **206** control functions and timing of the hardware in the probe, and depending upon implementation, can also perform digital signal processing of the digital signal output by the ADC **208**. For example, the digital control and processing block **206** can perform logarithmic compression, as was mentioned above. The digital control and processing clock **206** also controls the Tx/Rx controller **240**.

[0035] The Tx/Rx controller **240**, which can be implemented using an FPGA, an ASIC or some other circuitry, controls the Tx switches **222** so that a selected set of the MUTs transmit ultrasonic pulses generated by a high voltage (HV) pulser **224**. The host computer **112**, through the passive interface cable **106**, and the interface IC **204** can control the amplitude, frequency and duration of the pulses output by the HV pulser **224**. For example, the host computer **112** can write vector configuration and timing data to the memory **230**. Additionally, the host computer **112** can send instructions to the probe **102** that cause the probe **102** to select, from the memory **230**, specific transmit and receive vector control and timing data used to control transmission and reception of ultrasonic pulses.

[0036] The HV pulser **224** is powered by the HVPS **250**, which generates the high voltage potential(s) required by the HV pulser **224** from a lower voltage (e.g., 5V) received via the passive interface cable **106**. Depending upon implementation, the HV pulser **224** can produce unipolar pulses, or bipolar pulses. Unipolar pulses can be, e.g., high voltage pulses that are as large as 100V. Where the HV pulser **224** produces bipolar pulses, the HV pulser **224** may produce, e.g., both positive and negative high voltage pulses that can be as large as +/−100V. In such embodiments, the HVPS **250** can provide up to +/−100V supply rails to the HV pulser **224**. Exemplary details of an HVPS, which can be used to implement the HVPS **250**, are shown in and described with reference to FIG. 4 of U.S. Patent Publication No. 2007/0239019, which U.S. Patent Publication is incorporated herein by reference in its entirety. Alternative high voltage power supplies known in the art may also used as HVPS **250**.

[0037] The probe **102** can also include a linear regulator IC (now shown) with integrated power switches and low quiescent current requirements designed for USB applications. For example, such a linear regular IC can produce a 3.3V digital supply and a 3.3V analog voltage supply, which are used to provide power to the various circuits/blocks within the probe **102**. For example, a 3.3V digital supply can power the interface IC **204** and the digital control and processing block **206**; and a 3.3V analog supply can power the summing amplifier **212** and the analog signal processing circuitry **210**. An exemplary IC that can be used for the linear regulator IC is the TPS2148 3.3-V LDO and Dual Switch for USB Peripheral Power Management IC, available from Texas Instruments of Dallas, Tx.

[0038] Preferably, the probe **102** is configured as a single channel architecture, which means that only a single ADC **208** is required, and only a single data signal is transmitted from the probe **102** to the host **112** at any given time. However, in alternative embodiments, a multiple channel architecture that includes multiple ADCs can be implemented. Unless stated otherwise, the embodiments described herein include a single channel architecture. Another benefit of specific embodiments of the present invention is that the MUT array **220** is in close proximity to (i.e., within the same housing as) the analog summing, amplifying and processing circuitry **215** and the ADC **208** (see FIG. 2A). This provides for good signal-to-noise (S/N) ratio, as compared to systems where the analog signals output by the transducers must travel across a relatively long distance before they are amplified and/or digitized.

[0039] As mentioned above, the portable ultrasound imaging probe **102** includes an array of ultrasound transducers, which includes numerous transducers. In a preferred embodiment, the portable ultrasound imaging probe **102** includes a micromachined ultrasound transducer (MUT) array **220**, which includes numerous MUTs **221**, each of which can be referred to as an MUT element (or simply as an MUT). Each MUT element can include a single MUT cell, or multiple MUT cells hardwired together. Such a MUT array **220**, which can also be referred to as an array of MUTs, is an example of a MEMS based transducer, since the MUTs are examples of micro-electro-mechanical systems (MEMS). A MUT is one example of an ultrasound transducer. However, the principles of the present invention are also applicable to arrays of ultrasound transducers and ultrasound transducers other than MUTs. Thus, although the following description refers to MUTs, alternative ultrasound transducers and transducer arrays can be used in place of the MUTs and MUT arrays described below.

[0040] Each MUT cell can be a capacitive MUT (cMUT) cell or a piezoelectric MUT (pMUT) cell, but is not limited thereto. Such cells typically include a membrane (often referred to as a diaphragm) and two or more electrodes. For transmission, the electrodes and membrane are used to modulate a capacitive charge that vibrates the membrane and thereby transmits a sound wave. For reception, the electrodes and membrane are used to convert the sound vibration of a received ultrasound signal into a modulated capacitance. More specifically, when an AC signal is applied across the electrodes, the MUT generates ultrasonic waves in the medium of interest to thereby function as a transmitter. When ultrasonic waves are applied to the membrane of a MUT, the MUT generates an alternating signal as the capacitance of the MUT is varied to thereby function as a receiver of ultrasonic waves.

[0041] Each MUT element can simply be referred to as an MUT, and a plurality of MUT elements can simply be referred to as MUTs. Preferably, the MUT array **220** is encased in material that has the proper acoustic impedance to be matched with acoustic impedance of human tissue.

[0042] Advantageously, MUTs can be made using semiconductor fabrication processes, such as microfabrication processes generally referred to as "micromachining" Micromachining is the formation of microscopic structures using patterning, deposition and/or etching. Patterning generally includes lithography, which can be performed using projection-aligners or wafer-steppers, but is not limited thereto. Deposition can be physical vapor deposition (PVD), chemical vapor deposition (CVD), low-pressure chemical vapor deposition (LPCVD), or plasma chemical vapor deposition (PECVD), but is not limited thereto. Etching can include wet-chemical etching, plasma-etching, ion-milling, sputter-etching or laser-etching, but is not limited thereto.

[0043] Micromachining is typically performed on substrates or wafers made of silicon, glass, sapphire or ceramic. Such substrates or wafers are generally very flat and smooth and have lateral dimensions in inches. They are usually processed as groups in cassettes as they travel from process tool to process tool. Each substrate can advantageously (but not necessarily) incorporate numerous copies of a product. Micromachining can include the use of conventional or known micromachinable materials including silicon, sapphire, glass materials of all types, polymers (such as polyimide), polysilicon, silicon nitride, silicon oxynitride, thin film metals such as aluminum alloys, copper alloys and tungsten, spin-on-glasses (SOGs), implantable or diffused dopants and grown films such as silicon oxides and nitrides, but is not limited thereto.

[0044] In accordance with an embodiment, the MUT array **220** includes M rows×N columns of transducer elements, with the MUTs **221** being illustrated as small circles in FIG. 2A. For example, if M=20 and N=100, then the MUT array would include 2000 MUTs. In accordance with an embodiment, half of the MUTs **221** can be selectively used for transmitting ultrasonic pulses, and the other half of the MUTs **221** can be selectively used for receiving "echo pulses". Continuing with the example where the MUT array **220** includes 2000 MUTs, then 1000 of the MUTs **221** can be can be selectively used for transmitting ultrasonic pulses, and 1000 of the MUTs **221** can be selectively used for receiving "echo pulses". More generally, P1 percent of the MUTs can be selectively used for transmitting ultrasonic pulses, and P2 percent (where P2=100%−P1) of the MUTs can be selectively used for receiving "echo pulses". Unless specified otherwise, it will be assumed that P1=P2=50%, such that half of the MUTs can be selectively used for transmitting ultrasonic pulses, and half of the MUTs can be selectively used for receiving "echo pulses". For illustrative purposes, the MUTs that can be used for transmitting ultrasonic pulses, which can be referred to as Tx MUTs, are illustrated in FIG. **2**A as small filled circles **223**; and the MUTs that can be used for receiving ultrasonic pulses, which can be referred to as Rx MUTs, are illustrated in FIG. **2**A as small unfilled circles **225**.

[0045] Each of the MUTs **221** can have a circumferential shape that is circular, as shown. Each MUT **221** can be, e.g., about 50 micrometers in diameter, but is not limited thereto. The distance from the edge of one MUT **221** to its closest adjacent MUT **221** can be, e.g., about 70 micrometers, but is not limited thereto. Alternatively, each of the MUTs can have another circumferential shape, including, but not limited to, square or hexagonal. In accordance with certain embodiments, the Tx MUTs **223** and the Rx MUTs **225** are structurally the same. In such embodiments, the only difference between a Tx MUT **223** and an Rx MUT **225** is how the MUT is connected to other circuitry and used. In other embodiments, the Tx MUTs **223** can be structurally different from the Rx MUTs **225**. In alternative embodiments, each of MUTs **221** may be replaced with conventional ultrasound transducers which may be square or circular in shape (see, e.g. FIGS. **2**E and **2**F).

[0046] All of the rows and columns can be inline with one another, as shown in FIG. **2**A. Alternatively, odd rows can be staggered relative even rows, as shown in FIG. **2**D. It is also possible that odd columns be staggered relative to even columns. Other variations are also possible, and within the scope of an embodiment of the present invention. In the embodiment shown in FIG. **2**A, the Tx MUTs **223** and the Rx MUTs **225** alternate in a way that creates minimum pitch in linear array configuration, thereby enabling better lateral resolution.

[0047] As will be described in further detail below, at any given time, a set of the Tx MUTs **223** can be selected for transmitting ultrasonic pulses, and a set of the Rx MUTs **225** can be selected for receiving echo pulses. For example, sets of Tx MUTs **223** that collectively make up rings can be used to form a quasi-annular array transducer, as will be described below with reference to FIGS. **3**-**5**. Switches **222**, which can be referred to as Tx switches **222**, can be used to select which Tx MUTs **223** are active at a time. Similarly, switches **216**, which can be referred to as Rx switches, can be used to select which Rx MUTs **225** are active at a time. In accordance with an embodiment, each of the Tx MUTs **223** is connected to a corresponding Tx switch. When the Tx switch is turned on (which can also be referred to as closed), the Tx MUT **223** is connected by its corresponding Tx switch to the HV pulser **224**, thereby causing the Tx MUT **223** to output an ultrasonic pulse. When multiple MUTs **223** are triggered simultaneously (i.e., simultaneously connected by switches to the HV pulser **224**), the multiple MUTs collectively produce an ultrasonic pulse or wave-front.

[0048] Selected Tx MUTs **223** transmit ultrasonic pulses into the target region being examined, and selected Rx MUTs **225** receive reflected ultrasonic pulses (i.e., "echo pulses") returning from the region. When transmitting, the selected Tx MUTs **223** are excited to high-frequency oscillation by the pulses emitted by the HV pulser **224**, thereby generating ultrasound pulses that can be directed at a target region/object to be imaged.

[0049] These ultrasound pulses (also referred to as ultrasonic pulses) produced by the selected Tx MUTs **223** are echoed back towards the selected Rx MUTs **225** from some point within the target region/object, e.g., at boundary layers between two media with differing acoustic impedances. The echo pulses received by the selected Rx MUTs **225** are converted into corresponding low-level electrical input signals (i.e., the "echo signals") that are provided to the analog summing, amplification and processing circuitry **215**. In specific embodiments, to receive echo pulses, the Rx switches **216** selectively connect a set of the Rx MUTs **225** to summing resistors **214**, which are used to sum the echo pulses at the input of a summing amplifier **212**.

[0050] Advantageously, in certain embodiments, the vectors may be uploaded to memory (look-up-table) **230** from Host Computer **112** in order to upgrade probe **102** or provide a set of vectors suitable for a particular imaging application. For example different vectors can be provided for imaging different portions of the human body, different tissues, or different depths depending on the application. A user can select the appropriate application (imaging purpose) in the host computer **112** which can then transfer an appropriate vector set to memory **230** over passive interface cable **106** prior to imaging. Alternatively memory **230** can include a plurality of vector sets suitable for different applications and the user can select which of those vector sets is used by Tx/Rx Controller **215** in a particular imaging session by input to host computer **112** or using an interface/switch/multiposition switch on probe housing **103**. After download or selection of a pre-existing vector set in memory **230**, the vector set can be used by Tx/Rx Controller **215** to configure Tx switches **222** and Rx switches **216** to cause Tx MUTS **223** and Rx MUTS **225** to transmit and receive ultrasound pulses in accordance with the downloaded vectors suitable for the intended application.

[0051] FIG. **2**B illustrates some further details of some of the blocks introduced in FIG. **2**A, according to an embodiment of the present invention. In specific embodiments, to receive echo pulses, the Rx switches **216** selectively connect a set of the Rx MUTs **225** to summing resistors **214**, which are used to sum the echo pulses at the input of a summing amplifier **212**. In accordance with an embodiment, the analog summing, amplification and processing circuitry **215** includes summing resistors **214** and a summing amplifier **212**. Exemplary details of the Rx switches **216**, the summing resistors **214** and the summing amplifier **212** are shown in FIG. **2**B.

[0052] Note that, as previously discussed, single channel architecture is used. Accordingly, the Rx switches **216** (or Tx/Rx) switches connect a plurality of selected MUTS **225** to analog summing, amplification and signal processing circuitry **215**. Note that there are a plurality of summing resistors **214** in order that they may be connected to a selected plurality of Rx MUTS **225**. Analog summing, amplification and signal processing circuitry **215** is configured to combine the plurality of echo signals produced by the plurality of the ultrasound transducers **225** into a single analog echo signal. This can be achieved using summing amplifier **212**. A single analog-to-digital converter **208** (ADC) then converts the analog echo signal into a single digital echo signal for transmission to a host computer that can perform digital processing of the digital echo signal in order to display an ultrasound image.

[0053] FIG. **2**C illustrates a perspective view of a probe head assembly, according to an embodiment of the present invention. A shown in FIG. **2**C, MUT array **220** is positioned at the end of head assembly **105**. FIG. **2**C also shows a portion of the interface cable **209**, which is used to connect the components within the probe head assembly **105** to components within the probe housing **103**.

[0054] FIG. **2**D illustrates how odd and even rows of MUTS **221** can be staggered relative to one another. All of the rows and columns can be inline with one another, as shown in FIG. **2**A. Alternatively, odd rows can be staggered relative even rows, as shown in FIG. **2**D. It is also possible that odd columns be staggered relative to even columns. Other variations are also possible, and within the scope of an embodiment of the present invention. In the embodiment shown in FIG. **2**D, the Tx MUTs **223** and the Rx MUTs **225** alternate in a way that creates minimum pitch in linear array configuration, thereby enabling better lateral resolution. As mentioned above, sets of Tx MUTs **223** that collectively makes up rings/circles that can be used to form a quasi-annular array transducer, as described below with reference to FIGS. **3**A-**5**D.

[0055] FIG. **2**E illustrates an alternative array of ultrasound transducers according to an embodiment of the present invention. As shown in FIG. **2**E, an alternative ultrasound transducer array **260** includes a regular distribution of 128 rectangular ultrasound transducers **262** arranged in a linear array (single row). In alternative embodiments transducer array **260** may be square, rectangular, linear or another shape and may comprise one, or a plurality of, rows and/or columns of transducers. Transducer array **260** may comprise a different number of transducers depending on the application. For example, transducer array **260** may comprise 8, 16, 32, 64, 128, 256 or more transducers **262**. Transducers **262** may be any suitable shape for assembly into an array including for example, square, rectangular, or circular. Alternative transducer array **260** may be used in place of MUT array **220** in all embodiments described herein.

[0056] Transducer array **260** is preferably planar in shape i.e. all of transducers **262** lay in a single flat plane (not curved). Moreover, in preferred embodiments no lens or other beam forming device is placed over transducer array **260**. Accordingly, similar or identical ultrasound beams can be produced by similar groups of transducers **262** at different locations in transducer array **260**.

[0057] Transducers **262** can be made using conventional technology known in the art and may be, for example, piezoelectric transducers or capacitive transducers. In an embodiment ultrasound transducers **262** are substantially rectangular piezoelectric transducers approximately 5 mm by 0.3 mm in size. A set of 16 adjacent transducers acting together form a substantially square ultrasound source.

[0058] As shown in FIG. **2**F, Transducers **262** are selectively connected by Tx/Rx switches **266** to HV pulser **224** and analog processing circuitry **215**. Each of ultrasound transducers **262** may be used for transmitting ultrasound pulses or receiving ultrasound echoes depending on the configuration of the Tx/Rx switches **266** as controlled by Tx/Rx Controller **240**. Alternatively, certain transducers **262** may be used only for transmitting ultrasound pulses and other may be used only for detecting ultrasound echoes. In this alternative embodiment, switches Tx switches **222** and Rx switches **216** are used in place of Tx/Rx switches **266**.

[0059] Note that, as previously discussed, single channel architecture is used in combination with transducer array **260**. Accordingly, the Tx/Rx switches **266** (or Rx switches **216** in an alternative embodiment) connect the plurality of selected transducers **262** to analog summing, amplification and signal processing circuitry **215** which is configured to combine echo signals produced by a plurality of the ultrasound transducers **262** into a single analog echo signal. A single analog-to-digital converter (ADC) then converts the analog echo signal into a digital echo signal for transmission to a host computer that can perform digital processing of the digital echo signal in order to display an ultrasound image.

[0060] FIG. **2**F is a block diagram that shows details of an alternative ultrasonic imaging probe according to an embodiment of the present invention. FIG. **2**F has almost all the elements of FIG. **2**A as previously described. However MUT Array **220** has been replaced transducer array **260**. Additionally, Tx/Rx switches **266** are used in place of the Tx switches **222** and Rx switches **216** of FIG. **2**A such that each of the ultrasound transducers **262** may be used for transmitting or receiving ultrasound depending on the configuration of the Tx/Rx switches **266** at a particular point in time.

[0061] The Tx/Rx switches **266** can be used to connect a selected set of the transducers **262** to either the HV pulser **224**, or the analog summing, amplification and processing circuitry **215**, depending on whether the transducers **262** are to be used for transmitting or receiving ultrasound pulses at a particular time. When a high voltage pulse is produced by the HV pulser **224**, the Tx/Rx switches automatically block the high voltage from damaging the analog summing, amplification and processing circuitry **215**. When the HV pulser **224** is not producing a pulse, the Tx/Rx switches disconnect a selected set of transducers **262** from the pulser **224**, and instead connect a selected set of transducers **262** to the analog summing, amplification and processing circuitry **215**. Note that Tx/Rx switches **266** may also be used in combination with MUT array **220** (see, e.g. FIGS. **2**A and **2**D).

[0062] FIG. **3**A illustrates how sets of micromachined ultrasound transducers (MUTs) that collectively make up rings can be used to form a quasi-annular array transducer, and that such rings can be moved to emulate the mechanical movement of an annular array transducer, without requiring any moving parts. Referring to FIG. **3**A, illustrated therein are a plurality of possible MUT vectors, each of which is made up of a plurality of annular rings/circles of MUTs **221**. Each such vector can be made up of a plurality of different sets of MUTs **221**, wherein each set of MUTs defines a different annular ring/circle of MUTs **221**, as can be appreciated from the discussion of FIGS. **4**A-**4**D below. Still referring to FIG. **3**A, illustrated therein are four different MUT vectors, the first one of which is labeled Vector **1**, and the last one of which is labeled Vector X. If, e.g., X=128, that would mean that 128 of the annular array MUT vectors can be produced using the MUT array **220**. More specifically, by controlling the Tx and Rx switches **222** and **216** (in FIG. **2**A), the various MUT Vectors (1 through 128) can be selected, one after the other, to emulate an annular array (annular shaped ultrasound transmitter) that is mechanically moved through 128 different physical positions (as shown by arrow **300**). However, here there is no mechanical movement; but rather, different MUTs **221** are selected at sequential points in time in order to emulate the movement. Thus, by controlling the Tx switches **222** to select different groups of Tx MUTS **223** at different times, the transmitting group of transducers forms an ultrasound transmitter which effectively changes position within the array of transducers over time. Similarly by controlling the Rx switches **216** to select different groups of Rx MUTS **225** at different times, the receiving group of transducers forms an ultrasound receiver which effectively changes position within the array of transducers over time.

[0063] FIG. **3**B is a blown-up view of two of the closely spaced adjacent vectors, X/2 and X/2+1, shown in FIG. **3**A. FIG. **3**B shows a MUT array **220** which includes a plurality of MUTs **221**, some or all of which may function as Tx MUTs **223** and some or all of which may function a Rx MUTs **225**. The adjacent vectors X/2 and X/2+1 show how different groups of Tx MUTS **223** and Rx MUTS **225** are selected (by Tx switches **222** and Rx switches **216** configured by Tx/Rx controller **240**) for transmitting and receiving ultrasound pulses at different sequential periods in time. As, shown, in the embodiments shown in FIGS. **3**A and **3**B, the Tx MUTs **223** and the Rx MUTs **225** alternate in a way that creates minimum pitch in linear array configuration, thereby enabling better lateral resolution.

[0064] FIGS. **3**C-**3**F show how sets of ultrasound transducers **262** of ultrasound transducer array **260** of FIGS. **2**E and **2**F can be used to form a moving square array transducer according to an embodiment of the present invention. In each of FIGS. **3**C-**3**F the set **350**, **360**, **370**, **380** of transducers **262** connected by Tx/Rx switches to HV pulser **224** as indicated by shading of transducers **262**. Each set **350**, **360**, **370**, **380** of sixteen adjacent transducers operates as a single square ultrasound transmitter. Alternative shapes of transmitter may be configured from different sets of transducers **262**. As shown by FIGS. **3**C-**3**F the active set of transducers can be moved without mechanical movement merely by selecting different transducers **262** for inclusion in the active set at a particular time. Thus the portion or subarray of transducer array **260** that is emitting ultrasound can “walk” around transducer array **260** under the control of Tx/Rx switches **266** as configured by Tx/Rx Controller **240**. Likewise the size, shape, and/or position of the set of transducers **262** connected to analog processing circuitry **215** can also be changed from one period of time to the next.

[0065] FIGS. **4**A-**4**D illustrate how a transmit MUT vector can be used to transmit focused ultrasound beams. FIGS. **4**A-**4**D illustrates different sized groups of Tx MUTs **223** rings/circle of Tx MUTs **223**, which can collectively be used to generate one focused ultrasound beam. The different groups of Tx MUTS **223** and Rx MUTS **225** are selected (by Tx switches **222** and Rx switches **216** configured by Tx/Rx controller **240**) for transmitting and receiving ultrasound pulses at different sequential periods in time. More specifically, the ring **410** of Tx MUTs **223** shown in FIG. **4**A can be used to collectively transmit a first ultrasound pulse. A short programmed delay thereafter the ring **420** of Tx MUTs **223** shown in FIG. **4**B can be used to collectively transmit a second ultrasound pulse. A short programmed delay thereafter the ring **430** of Tx MUTs **223** shown in FIG. **4**C can be used to collectively transmit a third ultrasound pulse. And, a short programmed delay thereafter the circle **440** of Tx MUTs **223** shown in FIG. **4**D can be used to collectively transmit a fourth ultrasound pulse. These four ultrasound pulses, sequentially generated as mentioned above, collectively make up a focused ultrasound beam.

[0066] By controlling the Tx switches **222** to select different groups of Tx MUTS **223** at different times, the transmitting group of transducers forms an ultrasound transmitter which effectively changes shape and/or size and/or position over time. As shown in FIGS. **4A-4D**, the ring **410** in FIG. **4A** has the largest aperture, and the circle **440** in FIG. **4D** has the smallest/no aperture. In FIGS. **4A-4D**, the four different rings/circle **410**, **420**, **430**, **440**, do not overlap one another. However, in alternative embodiments, there can be overlap between the different rings/circle. In other words, a Tx MUT **223** can be included in more than one annular ring/circle.

[0067] FIGS. **5A-5D** illustrate how a receive MUT vector can be used to receive echo pulses generated in response to the focused ultrasound beam described with reference to FIGS. **4A-4D**. FIGS. **5A-5D** illustrates different sized circles of Rx MUTs **225**, which can collectively be used to receive echo pulses and produce an echo signal. More specifically, the circle **510** of Rx MUTs **225** shown in FIG. **5A** can be used to collectively receive a first echo pulse; a short programmed delay thereafter the circle **520** of Rx MUTs **225** shown in FIG. **5B** can be used to collectively receive a second echo pulse; a short programmed delay thereafter the circle **530** of Rx MUTs **225** shown in FIG. **5C** can be used to collectively receive a third echo pulse; and a short programmed delay thereafter the circle **540** of Rx MUTs **225** shown in FIG. **5D** can be used to collectively receive a fourth echo pulse. These four echo pulses collectively make up a received ultrasound echo.

[0068] By controlling the Rx switches **216** to select different groups of Rx MUTS **225** at different times, the receiving group of transducers forms an ultrasound receiver which effectively changes shape, size, or position within the array of transducers over time. As shown in FIGS. **5A-5D**, the circle **510** of Rx MUTs **225** in FIG. **5A**, which has the smallest diameter, will receive near field echoes. By contrast, the circle **540** of Rx MUTs **225** in FIG. **5D**, which has the largest diameter, will receive the deepest field echoes. In FIGS. **5A-5D**, the four different circles **510**, **520**, **530**, **540**, overlap one another. However, in alternative embodiments, there can be no overlap between the different circles. In other words, an Rx MUT **225** may or may not be included in more than one circle. Further, it is noted that sets of the Rx MUTs **225** can be selected in such a way that the active area of circular arrays can continuously increase with a controlled number of sampling cycles in order to optimize the resolution of the received signal from different depths.

[0069] Tx/Rx Controller **240** controls Tx switches **222** and Rx switches **216** to select different groups of Tx MUTs **223** and Rx MUTS **225** at different times for sending and receiving ultrasound transducers thereby allowing the MUT Array **220** to emulate an ultrasound receiver and ultrasound transmitter which effectively changes in shape, size, or position within the array of transducers over time. While the Tx MUT and Rx MUT vectors shown in FIGS. **4A-4D** and **5A-5D** include substantially circular and/or annular arrays, because of the flexibility provided by the MUT array **220**, the vectors can have alternative shapes, such as, but not limited to elliptical shapes. In alternative embodiments, the Tx MUTs **223** and Rx MUTs **225** can be selectively connected to produce other types of arrays, besides circular and/or annular arrays. In embodiments, the vectors are stored in memory (look-up-table) **230**.

[0070] Advantageously, the MUT array **220** and the circuitry used to select sets of the MUTs can provide a continuously variable aperture annular array. More specifically, such circuitry can be used to activate sets of MUTs in such a way that the active area of annular arrays will continuously shift in order to form ultrasound beams with variable focal points. In other words, the MUT array **220** can be used to perform beam forming and aperture control for each of a plurality of different MUT vectors. Advantageously, beam shapes and aperture shapes and sizes can be optimized for both transmit and receive signals.

[0071] In accordance with certain embodiments of the present invention, preprogrammed vector configuration and timing data that enables the various annular rings of Tx MUTs **223** shown in FIGS. **4A-4D** to be fired in sequence is stored in the memory **230**, e.g., in a LUT. Similar data used to controls selection/activation of Rx MUTs, as was described with reference to FIGS. **5A-5D**, is also stored in the memory **230** (see FIG. **2A**).

[0072] FIGS. **6A-6D** illustrate how a vectors can be used to receive echo pulses generated in response to an ultrasound beam using transducer array **260** of FIGS. **2E** and **2F**. FIGS. **6A-6D** illustrates different sized groups/subarrays **660**, **670**, **680**, **690** of ultrasound transducers **262** (shaded), which can collectively be used to receive echo pulses and produce an echo signal. More specifically, the subarray **660** of ultrasound transducers **262** shown in FIG. **6A** can be used to collectively receive a first echo pulse; a short programmed delay thereafter the subarray **670** of ultrasound transducers **262** shown in FIG. **6B** can be used to collectively receive a second echo pulse; a short programmed delay thereafter the subarray **680** of ultrasound transducers **262** shown in FIG. **6C** can be used to collectively receive a third echo pulse; and a short programmed delay thereafter the subarray **690** of ultrasound transducers **262** shown in FIG. **6D** can be used to collectively receive a fourth echo pulse. These four echo pulses collectively make up a received ultrasound echo.

[0073] By controlling the Tx/Rx switches **266** to select different groups of ultrasound transducers **262** (shaded) at different times, the receiving group of transducers forms an ultrasound receiver which effectively changes shape, size, or position within the array of transducers **260** over time. As shown in FIGS. **6A-6D**, the subarray **660** of ultrasound transducers **262** shown in FIG. **6A**, which has the smallest size, will receive near field echoes. By contrast, the subarray **690** of ultrasound transducers **262** shown in FIG. **6*d*D** which has the largest size will receive the deepest field echoes. The increasing subarray size effectively provides a variable aperture for receiving ultrasound echoes in order to enhance the resolution of the received signal from different depths. The variable aperture for receiving may be utilized with fixed or variable sizes of transmitting subarrays of ultrasound transducers.

[0074] In FIGS. **6A-6D**, the four different subarrays **660**, **670**, **680**, **690**, overlap one another. However, in alternative embodiments, there can be no overlap between the different subarrays. In other words, a transducer **262** may or may not be included in more than one subarray. Further, it is noted that subarrays of the transducers **262** can be selected in such a way that the active area of the subarray can continuously increase with a controlled number of sampling cycles in order to optimize the resolution of the received signal from different depths.

[0075] Tx/Rx Controller **240** controls Tx/Rx switches **266** (see FIG. **2F**) to select different groups of transducers **262** at different times for sending and receiving ultrasound transducers thereby allowing the ultrasound array **260** to emulate an ultrasound receiver and ultrasound transmitter which effectively changes in shape, size, or position within the array of transducers over time. Because of the flexibility provided by the transducer array **260**, the vectors can have alternative shapes. In embodiments, the vectors are stored in memory (look-up-table) **230**. Subarrays may comprise non-adjacent transducers **262**, i.e. within a region of transducer array **260** certain transducers may be active for receiving (or transmitting) ultrasound while other are inactive depending on the desired vectors.

[0076] As described above with respect to the figures, in an embodiment, the present invention provides a portable ultrasonic imaging probe **102** that is adapted to connect to a host computer **112** via a passive interface cable **106**. The portable ultrasound imaging probe **106** includes a probe head **105** including an array of ultrasound transducers, for example MUT Array **220**. The array may comprise one or more parallel rows of ultrasound transducers, or a different shaped distribution of a plurality of ultrasound transducers. The ultrasound transducers may be, for example, micromachined ultrasound transducers MUTS **221** or other ultrasound transducers known in the art.

[0077] The portable ultrasonic imaging probe **102** also includes a pulse circuit, for example, a high voltage (HV) pulser **224** adapted to energize two or more transducers to emit ultrasound. The portable ultrasonic imaging probe **102** also includes analog processing circuitry **215**, including for example summing amplifier **212**, and summing resistors **214**, configured to process electrical signals caused by ultrasound pulses received by two or more ultrasound transducers into an analog echo signal. One or more analog-to-digital converters (e.g. ADC **208**) converts the analog echo signal, output by the analog summing, amplification and signal processing circuitry, to a digital echo signal, and an interface circuit **204** transfers the digital echo signal across a passive interface cable to a host computer that can perform digital processing of the digital echo signal in order to display an ultrasound image.

[0078] The portable ultrasonic imaging probe **102** also includes a transmit/receive controller **215** connected to a plurality of transmit (Tx) switches **222** and a plurality of receive (Rx) switches **216** wherein the transmit/receive controller **215** selects which of said ultrasound transducers are in transmitting group and which of said ultrasound transducers are in the receiving group at any point in time. The transmit/receive controller **215** configures the plurality of transmit (Tx) switches **222** to connect a transmitting group of the ultrasound transducers to the (HV) pulser **224**. The transmit/receive controller **215** also configures a plurality of receive (Rx) switches **2'6** to connect a receiving group of the ultrasound transducers to the analog summing, amplification and signal processing circuitry **215**.

[0079] The portable ultrasonic imaging probe **102** operates such that which ultrasound transducers of the ultrasound transducer array are part of the receiving group and which are part of the receiving group is configurable and can be changed over time under the control of transmit/receive controller **215** in response. Transmit and receive (Tx/Rx) controller **240** accesses vector configuration and timing data stored within a memory **230** to identify which transducers should be activated for transmitting (transmitting group) or receiving ultrasound pulses (receiving group) and at what time.

[0080] In accordance with the vector configuration and timing data the transmitting group includes a first plurality of transducers at a first time, a second plurality of transducers different than the first plurality at a second time, and a third plurality of transducers different than the first plurality and the second plurality a third time. The configurable transmitting group functions as a configurable ultrasound transmitter which can change in shape, size or position within the transducer array over time. This allows, for example the ultrasound imaging probe **102** to: emit a focused ultrasound beam; change the depth or focus or position of focus of the ultrasound beam; perform ultrasound beam forming; scan the ultrasound beam without moving the head **105**; and/or form a variable aperture ultrasound transmitter; and use configurable aperture control.

[0081] In accordance with the vector configuration and timing data the receiving group includes a first plurality of transducers at a first time, a second plurality of transducers different than the first plurality at a second time, and a third plurality of transducers different than the first plurality and the second plurality a third time. The configurable receiving group functions as a configurable ultrasound receiver which can change in shape, size or position within the transducer array over time. This allows, for example the ultrasound imaging probe **102** to: change the size, shape, or position of the configurable ultrasound receiver over time (in relation, for example, to the timing of the emission of ultrasound pulses). The receiving group can be selected in such a way that the active area of receiving transducers can be configured and changed over a number of sampling cycles in order to optimize the resolution of the received signal from different depths, different tissues, and in different applications.

[0082] In alternative embodiments, rather than having half the MUTs **221** dedicated to functioning as Tx MUTs **223**, and half the MUTs **221** dedicating to functioning as Rx MUTs **225**, each of the MUTs **221** of the MUT array **220** can be capable of being used as either an Rx MUT **223** or a Tx MUT **225**. In such alternative embodiments, transmit/receive (Tx/Rx) switches (not shown) can be used in place of the Tx switches **222** and the Rx switches **216**. The Tx/Rx switches can be used to connect a selected set of the MUTs **221** to either the HV pulser **224** or the analog summing, amplification and processing circuitry **215** depending on whether the MUTs **221** are to be used for transmitting or receiving ultrasound pulses at a particular time. When a high voltage pulse is produced by the HV pulser **224**, the Tx/Rx switches would automatically block the high voltage from damaging the analog summing, amplification and processing circuitry **215**. When the HV pulser **224** is not producing a pulse, the Tx/Rx switches disconnect a selected set of MUTs **221** from the HV pulser **224**, and instead connect a selected set of MUTs to the analog summing, amplification and processing circuitry **215**. However, Tx/Rx switches are relatively expensive compared to switches required to perform only one of the Tx switching and Rx switching functions. Accordingly, the aforementioned embodiments where certain MUTs **221** are dedicated to transmission, and other MUTs **221** are dedicated to reception, such a configuration may be preferable where it is desirable to eliminate the need for expensive Tx/Rx switches.

[0083] The foregoing description of preferred embodiments of the present invention has been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations will be apparent to one of ordinary skill in the relevant arts. The above mentioned part numbers are exemplary, and are not meant to be limiting. Accordingly, other parts can be substituted for those mentioned above.

[0084] The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention for various embodiments and with various modifications that are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims and their equivalents.

What is claimed is:

1. A portable ultrasonic imaging probe that is adapted to connect to a host computer via a passive interface cable, the portable ultrasound imaging probe comprising:

a probe head including an array of ultrasound transducers;

a high voltage (HV) pulser adapted to energize two or more transducers to emit ultrasound;

analog summing, amplification and signal processing circuitry configured to combine echoes detected by two or more ultrasound transducers into a single analog echo signal;

a single analog-to-digital converter (ADC) that converts the analog echo signal, output by the analog summing, amplification and signal processing circuitry, to a digital echo signal; and

interface circuitry adapted to transfer the digital echo signal across a passive interface cable to a host computer that can perform digital processing of the digital echo signal in order to display an ultrasound image;

a plurality of transmit (Tx) switches configured to connect a transmitting group of the ultrasound transducers to the (HV) pulser;

a plurality of receive (Rx) switches configured to connect a receiving group of the ultrasound transducers to the analog summing, amplification and signal processing circuitry;

a transmit/receive controller connected to the plurality of transmit (Tx) switches and the plurality of receive (Rx) switches wherein the transmit/receive controller selects which of said ultrasound transducers are in the transmitting group and which of said ultrasound transducers are in the receiving group.

2. The portable ultrasonic imaging probe of claim **1**, wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the ultrasound imaging probe emits a focused ultrasound beam.

3. The portable ultrasonic imaging probe of claim **1**, wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the transmitting group of transducers forms an ultrasound transmitter which changes in position within the array of transducers between the first time, the second time and the third time.

4. The portable ultrasonic imaging probe of claim **1**, wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time, wherein the first plurality of transducers form a first annular cluster in said array of transducers;

a second plurality of transducers different than the first plurality at a second time, wherein the second plurality of transducers form a second annular cluster in said array of transducers; and

a third plurality of transducers different than the first plurality and the second plurality a third time, wherein the third plurality of transducers form a third annular cluster in said array of transducers;

wherein the first annular cluster has a larger aperture diameter than the second annular cluster, and the second annular cluster has a larger aperture than the third annular cluster such that the transmitting group of transducers forms a variable aperture ultrasound transmitter.

5. The portable ultrasonic imaging probe of claim **1**, wherein said receiving group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the receiving group of transducers forms an ultrasound receiver which changes in size between the first time, the second time and the third time.

6. The portable ultrasonic imaging probe of claim **1**, wherein said receiving group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the receiving group of transducers forms an ultrasound receiver which changes in position between the first time, the second time and the third time.

7. The portable ultrasonic imaging probe of claim **1**, wherein:

said transmitting group of ultrasound transducers comprises

  a first plurality of transducers at a first time,

  a second plurality of transducers different than the first plurality at a second time, and

  a third plurality of transducers different than the first plurality and the second plurality a third time; and

said receiving group of ultrasound transducers comprises

  a fourth plurality of transducers at a fourth time;

  a fifth plurality of transducers different than the fourth plurality at a fourth time; and

  a sixth plurality of transducers different than the fourth plurality and the fifth plurality at a sixth time.

8. The portable ultrasonic imaging probe of claim **1**, wherein said array of transducers comprises a plurality of ultrasound transducers arranged in a row.

9. The portable ultrasonic imaging probe of claim **1**, wherein said array of transducers comprises a plurality of ultrasound transducers arranged in plurality of parallel rows.

10. The portable ultrasonic imaging probe of claim **1**, wherein said transducers are micromachined ultrasound transducers (MUTs).

11. A portable ultrasonic imaging probe that is adapted to connect via a passive interface cable to a host computer that can perform digital processing in order to display an ultrasound image, the portable ultrasound imaging probe comprising:

a probe head including an array of ultrasound transducers;

a power circuit adapted to energize two or more transducers to emit ultrasound;

analog processing circuitry configured to combine echoes detected by two or more ultrasound transducers into an analog echo signal;

an analog-to-digital converter (ADC) that converts the analog echo signal, output by the analog signal processing circuitry, into a single channel digital echo signal; and

interface circuitry adapted to transfer the digital echo signal across a passive interface cable to the host computer for digital processing in order to display an ultrasound image;

a plurality of switches configured to connect a transmitting group of the ultrasound transducers to the power circuit and configured to connect a receiving group of the ultrasound transducers to the analog processing circuitry;

a transmit/receive controller connected to the plurality of switches, wherein the transmit/receive controller selects which of said ultrasound transducers are in the transmitting group and which of said ultrasound transducers are in the receiving group.

12. The portable ultrasonic imaging probe of claim **11**, wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the ultrasound imaging probe emits a focused ultrasound beam.

13. The portable ultrasonic imaging probe of claim **11**, wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the transmitting group of transducers forms an ultrasound transmitter which changes in position within the array of transducers between the first time, the second time and the third time.

14. The portable ultrasonic imaging probe of claim **11**, wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time, wherein the first plurality of transducers form a first annular cluster in said array of transducers;

a second plurality of transducers different than the first plurality at a second time, wherein the second plurality of transducers form a second annular cluster in said array of transducers; and

a third plurality of transducers different than the first plurality and the second plurality a third time, wherein the third plurality of transducers form a third annular cluster in said array of transducers;

wherein the first annular cluster has a larger aperture diameter than the second annular cluster, and the second annular cluster has a larger aperture than the third annular cluster such that the transmitting group of transducers forms a variable aperture ultrasound transmitter.

15. The portable ultrasonic imaging probe of claim **11**, wherein said receiving group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the receiving group of transducers forms an ultrasound receiver which changes in size between the first time, the second time and the third time.

16. The portable ultrasonic imaging probe of claim **11**, wherein said receiving group of ultrasound transducers comprises:

a first plurality of transducers at a first time;

a second plurality of transducers different than the first plurality at a second time; and

a third plurality of transducers different than the first plurality and the second plurality a third time;

whereby the receiving group of transducers forms an ultrasound receiver which changes in position between the first time, the second time and the third time.

17. The portable ultrasonic imaging probe of claim **11**, wherein:

said transmitting group of ultrasound transducers comprises

a first plurality of transducers at a first time,

a second plurality of transducers different than the first plurality at a second time, and

a third plurality of transducers different than the first plurality and the second plurality a third time; and

said receiving group of ultrasound transducers comprises

a fourth plurality of transducers at a fourth time;

a fifth plurality of transducers different than the fourth plurality at a fourth time; and

a sixth plurality of transducers different than the fourth plurality and the fifth plurality at a sixth time.

18. The portable ultrasonic imaging probe of claim **11**, wherein said array of transducers comprises a plurality of ultrasound transducers arranged in a row.

19. The portable ultrasonic imaging probe of claim **1**, wherein said array of transducers comprises a plurality of ultrasound transducers arranged in plurality of parallel rows.

20. The portable ultrasonic imaging probe of claim **1**, wherein said transducers are micromachined ultrasound transducers (MUTs).

21. A portable ultrasonic imaging probe that is adapted to connect via a USB cable to a host computer that can perform digital processing in order to display an ultrasound image, the portable ultrasound imaging probe comprising:

a probe head including an array of ultrasound transducers;

a power circuit adapted to energize two or more transducers to emit ultrasound;

analog processing circuitry configured to combine echoes detected by two or more ultrasound transducers into an analog echo signal;

an analog-to-digital converter (ADC) that converts the analog echo signal, output by the analog signal processing circuitry, into a single digital echo signal; and interface circuitry adapted to transfer the digital echo signal across said USB cable to the host computer for digital processing in order to display an ultrasound image;

a plurality of switches configured to connect a transmitting group of the ultrasound transducers to the power circuit and configured to connect a receiving group of the ultrasound transducers to the analog processing circuitry;

wherein said transmitting group of ultrasound transducers comprises:

a first plurality of transducers at a first time,

a second plurality of transducers different than the first plurality at a second time, and

a third plurality of transducers different than the first plurality and the second plurality a third time.

22. The portable ultrasonic imaging probe of claim **21** wherein said transmitting group of transducers forms an ultrasound transmitter which changes in position within the array of transducers between the first time, the second time and the third time.

23. The portable ultrasonic imaging probe of claim **21**, wherein:

the first plurality of transducers forms a first annular cluster in said array of transducers;

the second plurality of transducers form a second annular cluster in said array of transducers; and

the third plurality of transducers forms a third annular cluster in said array of transducers;

wherein the first annular cluster has a larger aperture diameter than the second annular cluster, and the second annular cluster has a larger aperture than the third annular cluster such that the transmitting group of transducers forms a variable aperture ultrasound transmitter.

24. The portable ultrasonic imaging probe of claim **21**, wherein said receiving group of ultrasound transducers comprises:

a fourth plurality of transducers at a fourth time;

a fifth plurality of transducers different than the fourth plurality at a fifth time; and

a sixth plurality of transducers different than the fourth plurality and the fifth plurality at a sixth time;

whereby the receiving group of transducers forms an ultrasound receiver which changes in size between the fourth time, the fifth time and the sixth time.

26. The portable ultrasonic imaging probe of claim **21**, wherein said receiving group of ultrasound transducers comprises:

a fourth plurality of transducers at a fourth time;

a fifth plurality of transducers different than the fourth plurality at a fifth time; and

a sixth plurality of transducers, different than the fourth plurality and the fifth plurality, at a sixth time;

whereby the receiving group of transducers forms an ultrasound receiver which changes in position between the fourth time, the fifth time and the sixth time.

27. The portable ultrasonic imaging probe of claim **21**, wherein said array of transducers comprises a plurality of ultrasound transducers arranged in a row.

28. The portable ultrasonic imaging probe of claim **21**, wherein said array of transducers comprises a plurality of ultrasound transducers arranged in plurality of parallel rows.

29. The portable ultrasonic imaging probe of claim **21**, wherein said transducers are micromachined ultrasound transducers (MUTs).

30. The portable ultrasonic imaging probe of claim **21**, in combination with said host computer and a USB cable connecting said interface circuitry to said host computer.

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摘要(译)

本发明提供了一种可直接连接到现成的膝上型计算机的便携式超声成像探头。探针产生原始数字化数据，包括来自超声换能器阵列的包络检测超声回波数据，并将数据发送到主计算机，从而使主计算机能够形成人体组织的实时超声图像，而无需任何附加电子设备。在特定实施例中，探针包括多个发射开关，其被配置为将超声换能器的发射组连接到脉冲发生器;多个接收开关，用于将超声换能器的接收组连接到模拟求和，放大和信号处理电路;发送/接收控制器，其选择所述超声换能器中的哪一个在发送组中，以及哪个所述超声换能器在接收组中。超声换能器可以是常规或微机械超声换能器。