US 20060058667A1

(19) United States
(12) Patent Application Publication (10) Pub. No.: US 2006/0058667 A1
Lemmerhirt et al. (43) Pub. Date: Mar. 16, 2006

(54) INTEGRATED CIRCUIT FOR AN ULTRASOUND SYSTEM

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(21) Appl. No.: **11/229,197**

(22) Filed: **Sep. 15, 2005**

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/840,548, filed on May 6, 2004.

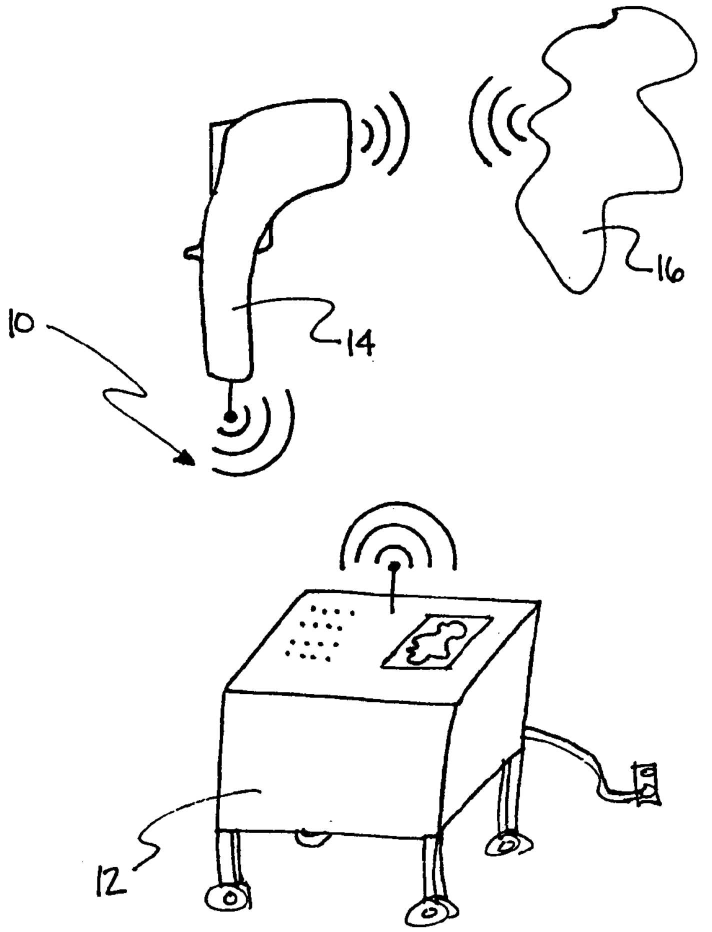
(60) Provisional application No. 60/610,320, filed on Sep. 15, 2004. Provisional application No. 60/610,319, filed on Sep. 15, 2004. Provisional application No. 60/610,337, filed on Sep. 15, 2004.

Publication Classification

(51) **Int. Cl.**
A61B 8/14 (2006.01)
(52) **U.S. Cl.** **600/446**

(57) **ABSTRACT**

The preferred embodiment of the invention includes a single integrated circuit for a handheld probe of an ultrasound system. The integrated circuit includes a two-dimensional array of at least 512 transducer cells, each transducer cell is adapted to receive a beam signal, generate an ultrasonic beam, detect an ultrasonic echo at multiple locations, and combine the ultrasonic echoes into a single multiplexed echo signal. Each transducer cell includes at least one ultrasonic beam generator and at least four ultrasonic echo detectors. The integrated circuit also includes a series of beam signal leads adapted to carry the beam signals to the transducer cells and a series of echo signal leads adapted to carry the multiplexed echo signals from the transducer cells.



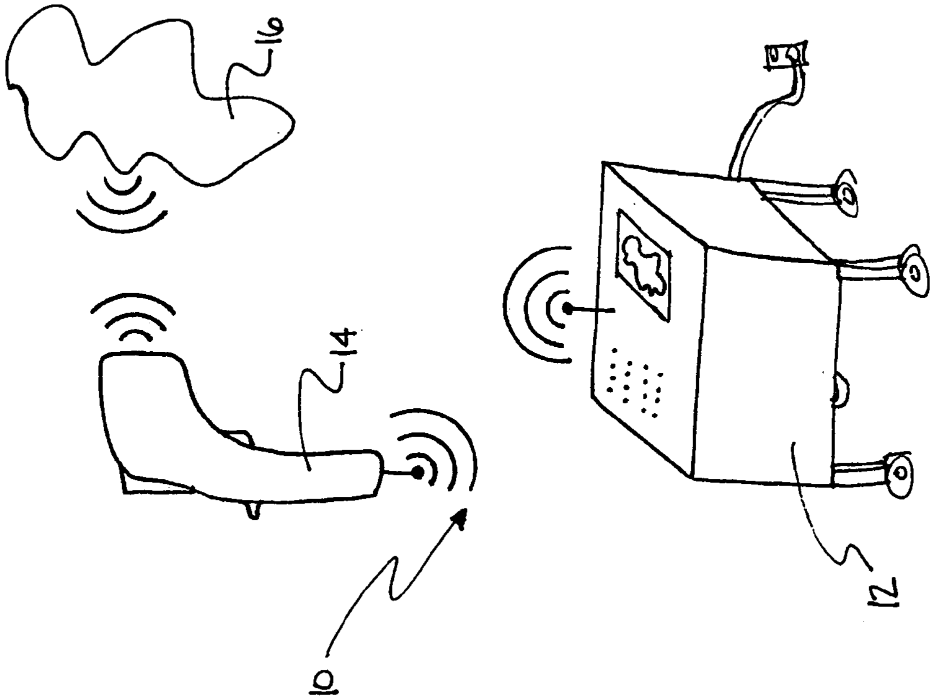


FIGURE 1

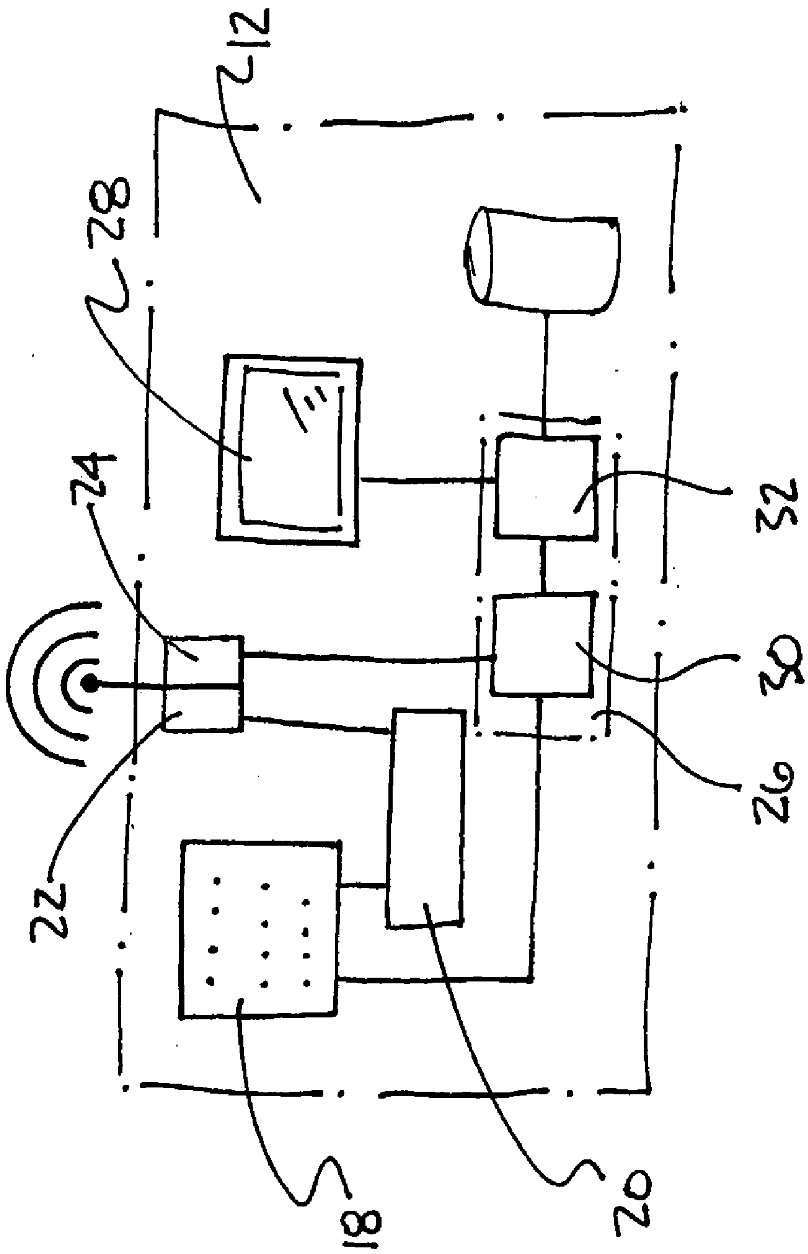


FIGURE 2

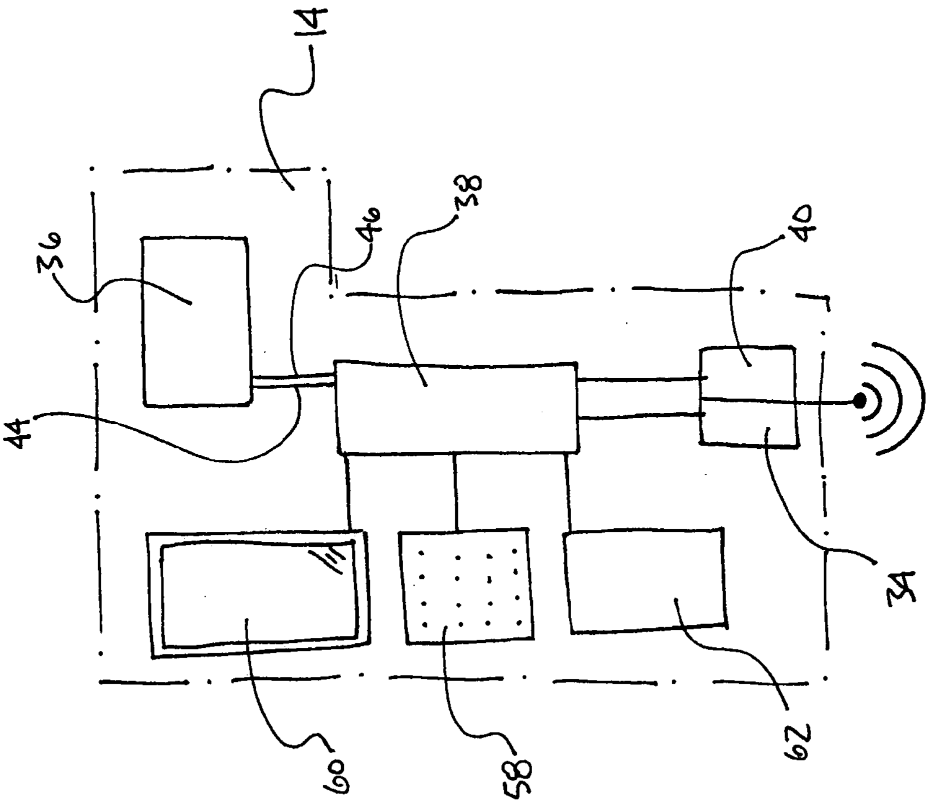


FIGURE 3

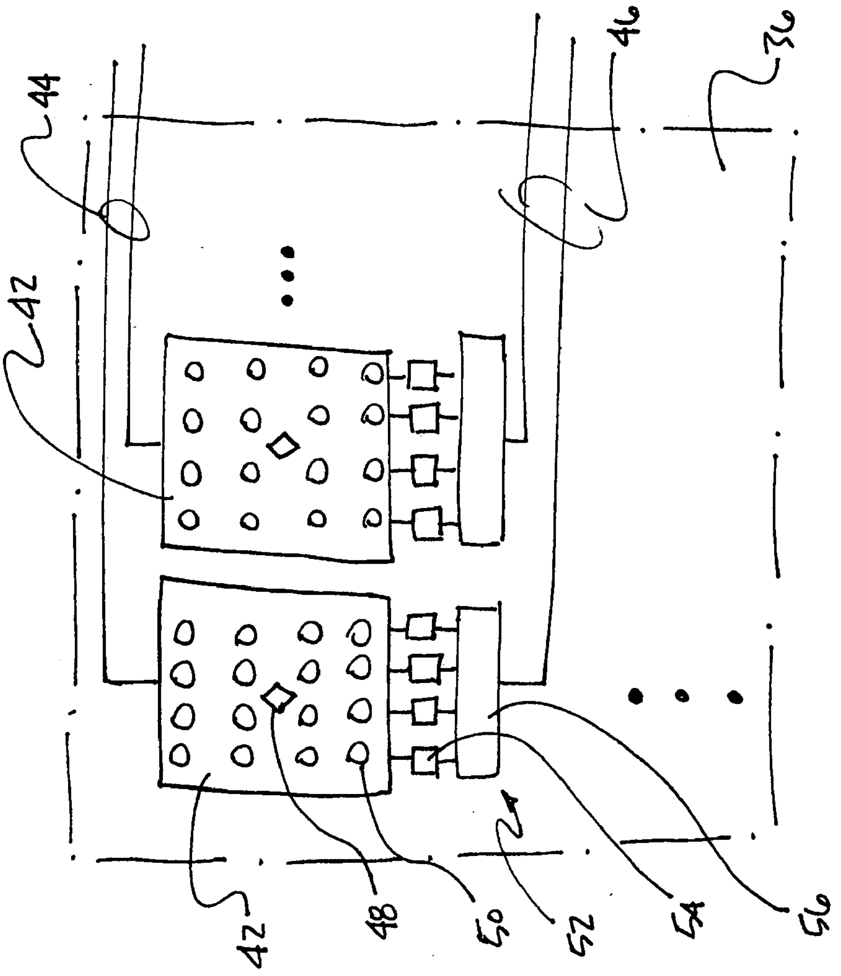


FIGURE 4

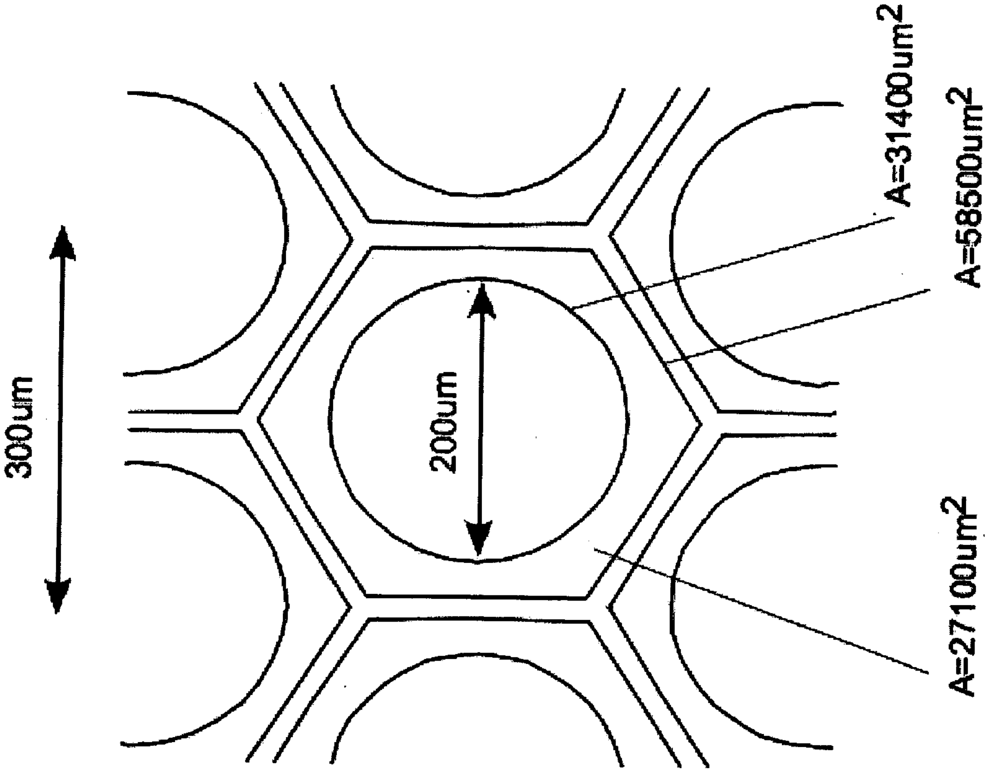


FIGURE 5

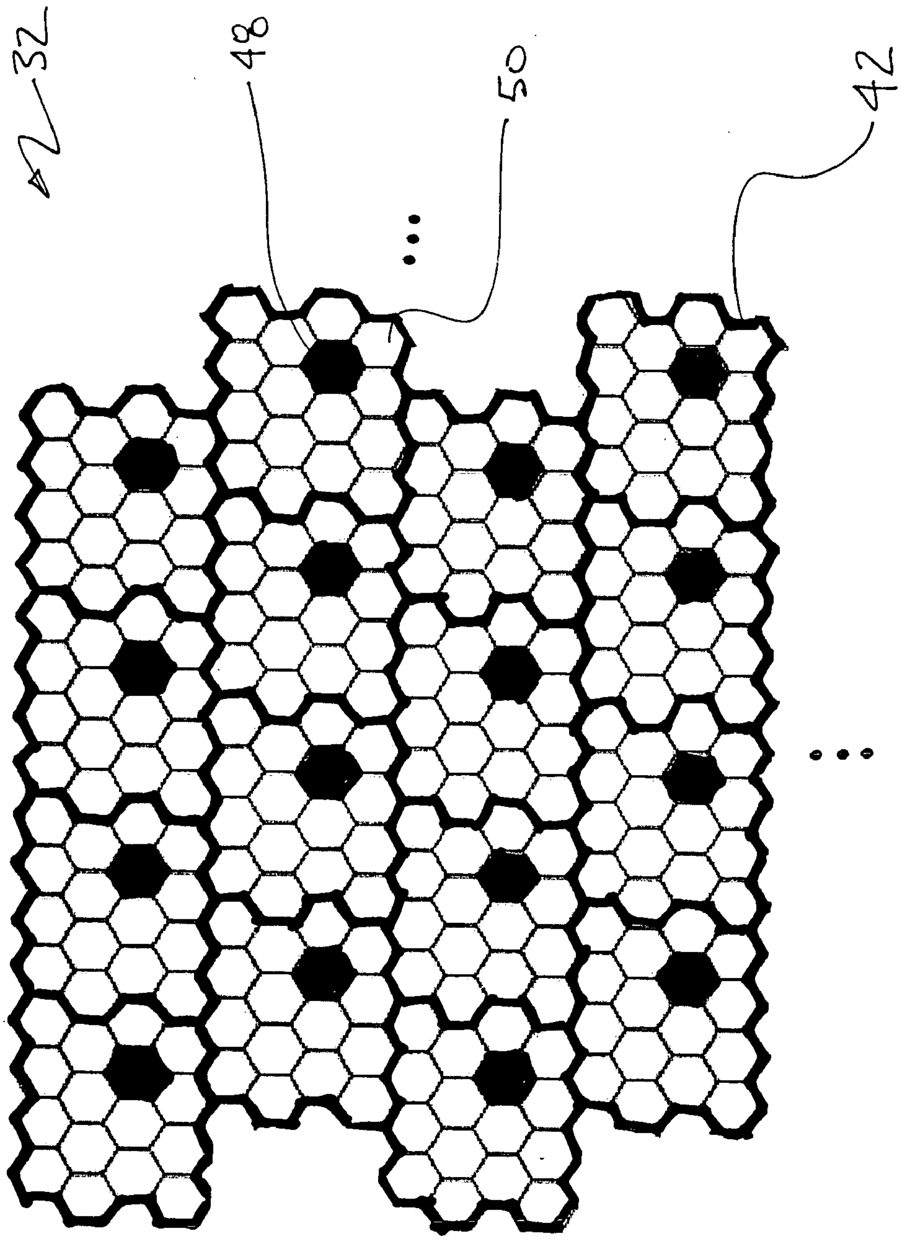


FIGURE 6

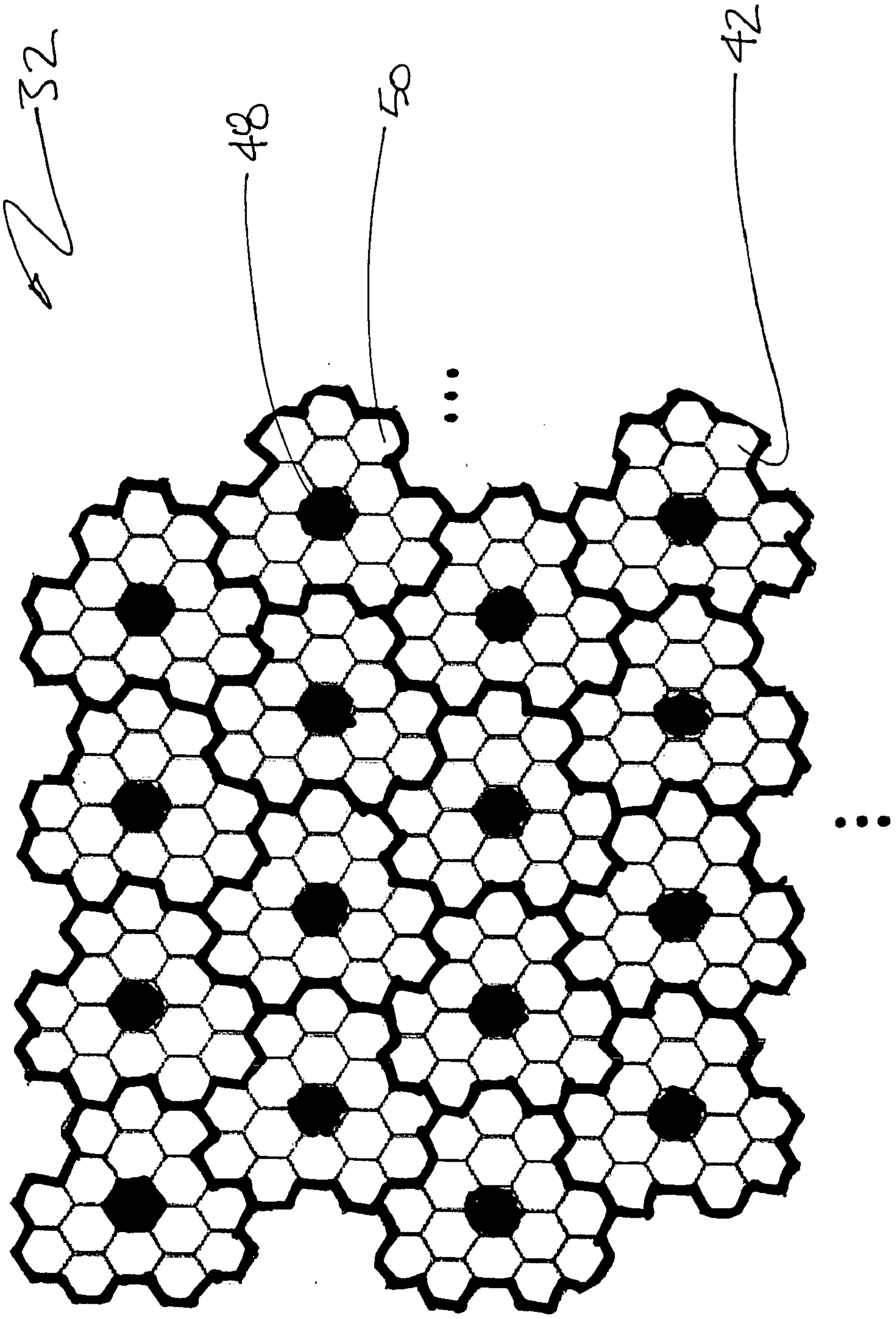


FIGURE 7

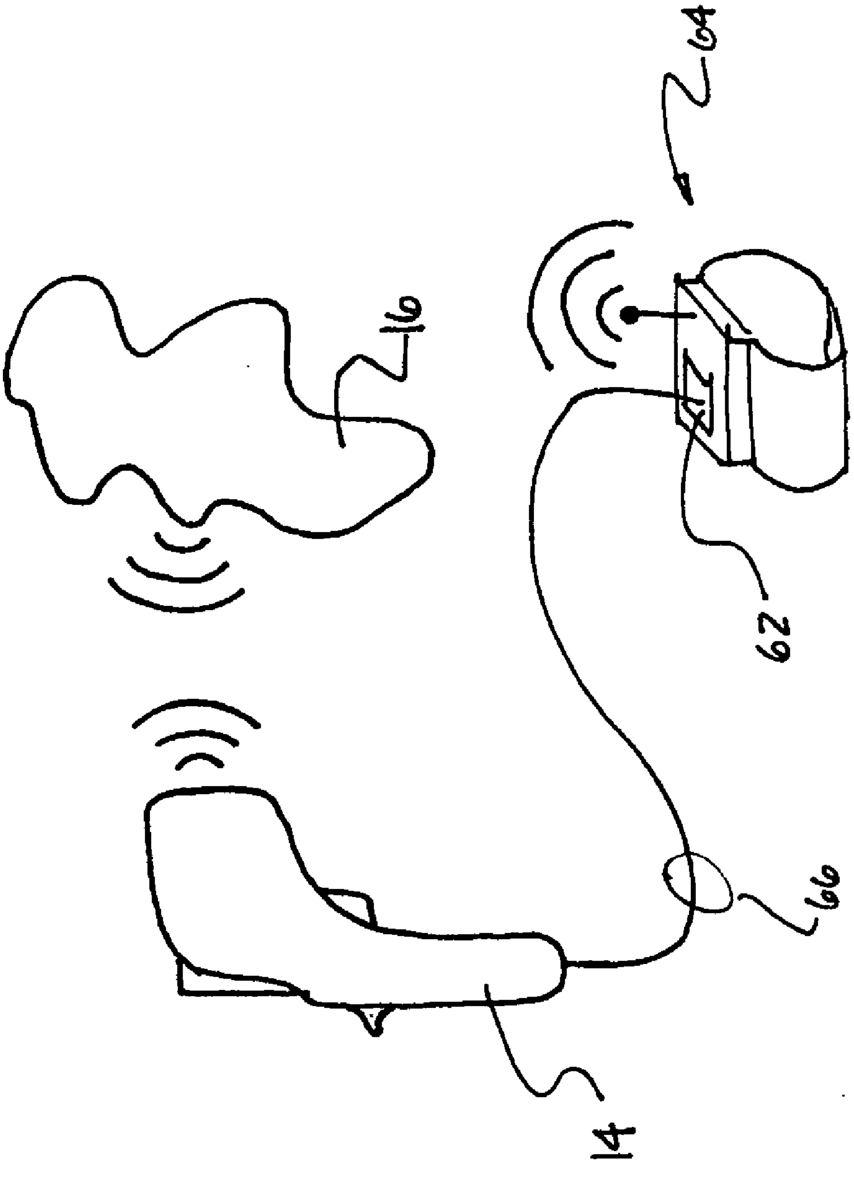


FIGURE 8

INTEGRATED CIRCUIT FOR AN ULTRASOUND SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present invention claims priority to the following three provisional applications: U.S. Provisional Patent Application No. 60/610,320 filed 15 Sep. 2004 and titled "Beamforming", U.S. Provisional Patent Application No. 60/610,319 filed 15 Sep. 2004 and titled "Transducer", and U.S. Provisional Patent Application No. 60/610,337 filed 15 Sep. 2004 and titled "Electronics".

[0002] The present invention also claims priority to U.S. Ser. No. 10/840,548 filed on 06 May 2004 and titled "Ultrasound System Including a Handheld Probe", which claims priority to the following four provisional applications: U.S. Provisional Patent Application No. 60/468,021 filed 06 May 2003 and titled "Wireless Transducer Head for Medical Ultrasound Systems", U.S. Provisional Patent Application No. 60/468,022 filed 06 May 2003 and titled "Two-Dimensional Array Design for Three-Dimensional Ultrasonic Imaging", U.S. Provisional Patent Application No. 60/468,023 filed 06 May 2003 and titled "Medical Ultrasound System Control Integral to the Transducer Head", and U.S. Provisional Patent Application No. 60/468,024 filed 06 May 2003 and titled "Three-Dimensional Ultrasonic Imaging System."

[0003] Each of the eight applications (the one application and the seven provisional applications) are incorporated in their entirety by this reference.

TECHNICAL FIELD

[0004] This invention relates generally to the medical field, and more specifically to an improved ultrasound system including a handheld probe.

BACKGROUND

[0005] Current medical ultrasound systems typically consist of a transducer head tethered by a communication cable to a central console, which includes the process controls for the ultrasound system. The transducer head generates acoustic waves and detects the reflected echo from the subject being insonified. The central console provides data processing and storage, image display, and/or other such functions typically required during an ultrasound examination.

[0006] The communication cable connecting the transducer head and the central console, although a necessity for existing ultrasound systems, can become a significant nuisance to the operator. The cable adds additional weight to the transducer head, which can tire the arm and wrist of the operator after long use. The cable often twists upon itself, which requires the operator—typically a highly paid sonographer or radiologist—to spend time untwisting the cable. Finally, the cable can become entangled with an injured patient or protruding pieces of delicate equipment.

[0007] There are, however, several obstacles that prevent the simple substitution of a wireless link for the communication cable of typical medical ultrasound systems. One is related to the physical distance between the transducer head and the central console; the other is related to the hardware of the transducer head.

[0008] The length of the communication cable between the transducer head and the central console of typical medical ultrasound systems is relatively short. In this manner, if the operator is holding the transducer head, the operator can reach and operate the process controls (e.g., imaging mode and frame or cine capture) on the central console. If the transducer head were wirelessly linked to the central console, however, the operators would not necessarily be within reach of the central console simply because they are holding the transducer head. Therefore, there exists a need to allow operation of an ultrasound system during a patient examination without requiring physical proximity to the central console.

[0009] Since the 1950s, ultrasound imaging has progressed from simple, analog A-mode imaging to far more sophisticated digital B-mode and color Doppler systems. Although these advancements have resulted in high-quality, 2D real-time imagers, an extension of this technology to produce 3D real-time images of comparable or vastly improved quality has not yet been realized. 3D ultrasound would allow medical specialists to view anatomy and pathologic conditions as a volume, thereby enhancing comprehension of the subject patient.

[0010] A 2D transducer array is universally acknowledged as the ideal approach for 3D ultrasound image acquisition. A single 3D frame volume from a 2D array, however, may contain gigabytes of raw data from a modest subject (e.g., an 8,000 cm^3 frame volume at 0.1 mm resolution) and frame rates for real-time imaging could exceed tens of frames per second. Such large amounts of data cannot be processed in real time by the hardware and software architecture typically used for typical ultrasound systems (e.g., 2D imaging with a 1D array). Collecting, pre-processing, and wirelessly transmitting this amount of data from a handheld probe is not currently possible with a transducer head of typical ultrasound systems.

[0011] Thus, there is a need in the medical field to create an improved ultrasound system with a handheld probe that collects enough echo data for 3D imaging and that transmits the echo data by a wireless link.

BRIEF DESCRIPTION OF THE FIGURES

[0012] **FIG. 1** is a representation of an ultrasound system of the preferred embodiment;

[0013] **FIG. 2** is a schematic representation of the central console of the ultrasound system;

[0014] **FIG. 3** is a schematic representation of a handheld probe for the ultrasound system;

[0015] **FIG. 4** is a schematic representation of a first example of an integrated circuit for the handheld probe;

[0016] **FIG. 5** is a representation of the relative size and proportion of the elements of the integrated circuit;

[0017] **FIGS. 6 and 7** are schematic representations of two variations of a second example of an integrated circuit for the handheld probe; and

[0018] **FIG. 8** is a representation of an alternative handheld probe for the ultrasound system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] The following description of the preferred embodiment of the invention is not intended to limit the invention to this preferred embodiment, but rather to enable any person skilled in the art of medical devices to make and use this invention.

[0020] The preferred embodiment of the invention include an ultrasound system, a handheld probe of the ultrasound device, and an integrated circuit for the handheld probe of the ultrasound system. The ultrasound system **10** of the preferred embodiment, as shown in **FIG. 1**, includes a central console **12** and a handheld probe **14**. The handheld probe **14** is adapted to receive a wireless beam signal from the central console **12**, generate an ultrasonic beam, detect an ultrasonic echo at multiple locations, combine the ultrasonic echoes into a single multiplexed echo signal, and transmit a multiplexed echo signal to the central console **12**. The ultrasound system **10**, including the handheld probe and the integrated circuit, provides an improved ultrasound system that collects enough echo data for 3D imaging and that transmits the echo data by a wireless link to overcome the limitations and drawbacks of typical ultrasound systems.

[0021] The ultrasound system **10** has been specifically designed to allow medical specialists to view the anatomy and pathologic conditions of a patient. The ultrasound system **10** may, however, be used to view any subject **16** that at least partially reflects ultrasound beams. Such non-medical uses may include ultrasonic microscopy, non-destructive testing, and other situations that would benefit from a volumetric imaging of the subject **16**.

[0022] The central console **12** of the preferred embodiment functions to: provide interaction with the operator of the ultrasound system **10**; wirelessly communicate with the handheld probe **14**; control the ultrasonic beams of the handheld probe **14**; process the 3D images from the multiplexed echo signals of the handheld probe **14**; and display a 3D image. The central console **12** may further provide other functions, such as providing data storage, data compression, image printouts, format conversions, communication links to a network, or any other appropriate function. To accomplish the five main functions, the central console **12** is conceptually separated into console controls **18**, a beam controller **20**, a console transmitter **22** and console receiver **24**, an image processor **26**, and a console display **28**, as shown in **FIG. 2**. The central console **12** is preferably designed as a mobile unit (such as a wheeled cart or a laptop computer), but may alternatively be designed as a fixed unit (such as a cabinet structure).

[0023] The console controls **18** of the central console **12** provide interaction with the operator of the ultrasound system **10**. The console controls **18** preferably allow the operator to configure the ultrasound system **10**, to switch between imaging modes, and to capture frame/cine. The console controls **18** may alternatively provide other appropriate functions. Input from the operator is collected, parsed, and sent to the image processor **26** and/or the beam controller **20** as appropriate. The console controls **18** may include knobs, dials, switches, buttons, touch pads, fingertip sensors, sliders, joysticks, keys, or any other appropriate device to provide interaction with the operator.

[0024] The beam controller **20** of the central console **12** controls the ultrasonic beams of the handheld probe **14**. The operator of the ultrasound system **10**, through the console controls **18** described above, may select a particular imaging mode (e.g., 3D, 2D slice, or local image zoom) for a subject **16**. To comply with this selection, the beam controller **20** preferably creates a beam signal that adjusts or modulates the frequency, sampling rate, filtering, phasing scheme, amplifier gains, transducer bias voltages, and/or multiplexer switching of the handheld probe **14**. Alternatively, the beam controller **20** may create two or more signals that adjust or modulate these parameters. Further, the beam controller **20** may create a beam signal that adjusts or modulates other appropriate parameters of the handheld probe **14**.

[0025] The console transmitter **22** and the console receiver **24** of the central console **12** function to provide a wireless communication link with the handheld probe **14**. Specifically, the console transmitter **22** functions to transmit beam signals to the handheld probe **14**, while the console receiver **24** functions to receive echo signals from the handheld probe **14**. In the preferred embodiment, the console transmitter **22** and the console receiver **24** use radiofrequency (RF) communication and an appropriate protocol with a high data throughput. In an alternative embodiment, however, the console transmitter **22** and the console receiver **24** may use infrared or other high-speed optical communication instead of, or in addition to, RF communication. The console transmitter **22** and the console receiver **24** may incorporate frequency hopping, spread-spectrum, dual-band, encryption, and/or other specialized transmission techniques known in the art to ensure data security and/or integrity in noisy environments. In the preferred embodiment, the console transmitter **22** and the console receiver **24** are located within different housings and are operated at different frequencies. In an alternative embodiment, the console transmitter **22** and the console receiver **24** may be combined (as a console transceiver) and/or may operate within the same channel or frequency.

[0026] The image processor **26** of the central console **12**, which functions to construct 3D images from the multiplexed echo signals of the handheld probe **14**, is preferably composed of a frame compiler **30** and an image engine **32**. The frame compiler **30** of the image processor **26** functions to assemble a single 3D image (or 3D frame) from the multiplexed echo signals of the handheld probe **14**. The echo signals, which are a series of pulses with specific time, amplitude, and phasing information, are correlated, summed, and transformed into voxels for the 3D image. Noise reduction, phase deaberration, contrast enhancement, orthogonal compounding, and other operations are also performed at this stage. In the preferred embodiment, as much as possible, these operations are performed in parallel fashion with dedicated algorithms, thus allowing the frame compiler **30** to be optimized for maximum speed. The frame compiler **30** preferably consists of a massively parallel set of lower-cost, medium-performance DSP cores, but may alternatively include other appropriate devices.

[0027] The image engine **32** of the image processor **26** receives complete frames from the frame compiler **30** and provides all higher-level processing (such as image segmentation) of the 3D frames. In the preferred embodiment, the image engine **32** also serves as a collection point for all echo data in the ultrasound system **10**. The image engine **32** preferably consists of a high-performance, highly programmable DSP core, but may alternatively include other appropriate devices. In an alternative embodiment, the image processor **26** may include other appropriate devices to construct 3D images from the multiplexed echo signals of the handheld probe **14**.

[0028] The console display **28** functions to present an image of the subject **16** to the operator in a form that facilitates easy and intuitive manipulation, navigation, measurement, and quantification. Examples of display modes include 3D, semi-transparent rendering, and 2D slices through the 3D structure. The console display **28** preferably includes a conventional LCD screen, but may alternatively include any appropriate device (such as a holographic or stereoscopic device) to present the scanned images.

[0029] The handheld probe **14** of the preferred embodiment functions to: wirelessly receive beam signals from the central console **12**; generate an ultrasonic beam and detect an ultrasonic echo at multiple locations; combine the ultrasonic echoes into a single multiplexed echo signal; and wirelessly transmit the echo signals to the central console **12**. The handheld probe **14** may further provide other functions, such as providing data storage, data compression, or any other appropriate function. To accomplish the four main functions, the central console **12** is conceptually separated into a probe receiver **34**, a first integrated circuit **36**, a second integrated circuit **38**, and a probe transmitter **40**, as shown in **FIG. 3**.

[0030] The probe receiver **34** and the probe transmitter **40** of the handheld probe **14** function to provide a wireless communication link with the central console **12**. Specifically, the probe receiver **34** functions to receive beam signals from the central console **12**, while the probe transmitter **40** functions to transmit a multiplexed echo signal to the central console **12**. The probe receiver **34** and the probe transmitter **40** use the same communication method and protocol as the console transmitter **22** and the console receiver **24**. In the preferred embodiment, the probe receiver **34** and the probe transmitter **40** are located within different housings. In an alternative embodiment, the probe receiver **34** and the probe transmitter **40** may be combined (as a probe transceiver).

[0031] The first integrated circuit **36** of the handheld probe **14** functions to generate an ultrasonic beam, detect an ultrasonic echo at multiple locations, and to combine the ultrasonic echoes into multiplexed echo signals. The first integrated circuit **36** preferably accomplishes these functions with the use of a 2D array of transducer cells **42**, a series of beam signal leads **44** that are adapted to carry the beam signals to the transducer cells **42**, and a series of echo signal leads **46** that are adapted to carry the multiplexed echo signals from the transducer cells **42**, as shown in **FIG. 4**. The first integrated circuit **36** may alternatively accomplish these functions with other suitable devices.

[0032] Each transducer cell **42** of the first integrated circuit **36**, which functions as a 2D phased subarray to scan one sector of the entire viewing field, preferably includes at least one ultrasonic beam generator **48**, at least four (and preferably fifteen or sixteen) ultrasonic echo detectors **50**, and at least one first multiplexer **52**. The ultrasonic beam generator **48** and the ultrasonic echo detectors **50** of the transducer cell **42** function to generate an ultrasonic beam and to detect an ultrasonic echo at multiple locations, respectively. Preferably, the ultrasonic beam generator **48** and the ultrasonic echo detectors **50** are separate elements, which simplifies the front-end electronics for the first integrated circuit **36** and allows the ultrasonic beam generator **48** and the ultrasonic echo detectors **50** to be separately optimized for their individual function. For example, the ultrasonic beam generator **48** may be optimized for high output (with increased ruggedness), while the ultrasonic echo detector **50** may be optimized for high sensitivity. This separate optimization may reduce edge wave effects (since a single point source can be fired instead of a complete subaperture). Although separate elements, the ultrasonic beam generator **48** and the ultrasonic echo detector **50** preferably share a basic shape and construction and preferably differ only by the diaphragm diameter, thickness, tensile stress, gap spacing, control electronics, and/or electrode configuration. Alternatively, the ultrasonic beam generator **48** and the ultrasonic echo detectors **50** may be formed as the same component (i.e., dual-function transducers). If the first integrated circuit **36** is operating at 3 MHz, the ultrasonic beam generator **48** and the ultrasonic echo detectors **50** have a preferred diameter of 100-200 μm and a preferred pitch of approximately 250±50 μm, as shown in **FIG. 5**. The ultrasonic beam generator **48** and the ultrasonic echo detectors **50** may, however, have any suitable diameter and pitch.

[0033] The first multiplexer **52** of the transducer cell **42** functions to combine the ultrasonic echoes from the ultrasonic echo detectors **50** into a multiplexed echo signal. To collect enough echo data for 3D imaging, the first integrated circuit **36** preferably includes at least 4,096 ultrasonic echo detectors **50**, more preferably includes at least 15,360 ultrasonic echo detectors **50**, and most preferably includes at least 16,384 ultrasonic echo detectors **50**. From a manufacturing standpoint, the number of echo signal leads **46** between the first integrated circuit **36** and the second integrated circuit **38** is preferably equal to or less than 1024 connections, and more preferably equal to or less than 512 connections. Thus, the first multiplexer **52** preferably combines the echo signals at least in a 4:1 ratio. The first multiplexer **52** may use time division multiplexing (TDM), quadrature multiplexing, frequency division multiplexing (FDM), or any other suitable multiplexing scheme. Further, the first multiplexer **52** may actually be two multiplexers (indicated in **FIG. 4** as a first portion **54** and a second portion **56**) combined that either use the same or different multiplexing schemes.

[0034] In a first example of the preferred embodiment, the transducer cell **42** is square shaped and the first integrated circuit **36** includes 1,024 transducer cells **42** (preferably arranged in a square pattern with thirty-two transducer cells **42** along one dimension and thirty-two transducer cells **42** along another dimension). Preferably, each transducer cell **42** includes: sixteen ultrasound echo detectors **50** (plus one ultrasound beam generator **48** and one first multiplexer **52**) in a transducer cell, and 1,024 transducer cells **42** in the first integrated circuit **36**. This arrangement provides a manageable level of echo signal leads **46** to the second integrated circuit **38** (1,024 echo signal leads), while providing enough echo data (16,384 ultrasonic echo detectors **50**) for 3D image rendering. The first multiplexer **52**, in this arrangement, combines sixteen echo signals into one multiplexed echo signal using a 16:1 TDM device. In a variation of this example, the first multiplexer **52** combines only four echo signals into one multiplexed echo signal using a 4:1 TDM device. Since there are four multiplexed echo signals and only one echo signal lead, the first integrated circuit of this example performs four passes, each pass with a new beam signal and each pass with only ¼th of the ultrasonic echo detectors **50** contributing to the echo signal. In this manner, the first multiplexer **52** is only combining a portion of the echo signals into a multiplexed signal.

[**0035**] In a second example of the preferred embodiment, as shown in **FIG. 5**, the transducer cell **42** is roughly rectangular shaped and the first integrated circuit **36** includes 1,024 transducer cells **42** (preferably arranged in a square pattern with thirty-two transducer cells **42** along one dimension and thirty-two transducer cells **42** along another dimension). Preferably, each roughly rectangular transducer cell **42** includes: one ultrasound beam generator **48** near the center, fifteen ultrasound echo detectors **50**, and one first multiplexer (not shown). The ultrasound beam generators **48** are preferably arranged in a regular hexagonal tessellation, but may alternatively be arranged in any suitable pattern. This arrangement provides a manageable level of echo signal leads to the second integrated circuit (1,024 echo signal leads), while providing enough echo data (15,360 ultrasonic echo detectors **50**) for 3D image rendering. The first multiplexer, in this arrangement, combines fifteen echo signals into one multiplexed echo signal using a 15:1 TDM device (potentially implemented as a 16:1 device, or as two 4:1 devices, with one repeated or null signal). In a variation of this second example, as shown in **FIG. 7**, the transducer cell **42** is roughly snowflake shaped. Preferably, each roughly snow-flaked shaped transducer cell **42** includes: one ultrasound beam generator **48** in the center, fifteen ultrasound echo detectors **50** (arranged as six "interior" ultrasound echo detectors **50** and nine "exterior" ultrasound echo detectors **50**), and one first multiplexer (not shown).

[**0036**] Since the first integrated circuit **36** is preferably limited to electronics that are essential to getting signals on- and off-chip, the first integrated circuit **36** may be manufactured by a standard low-cost CMOS process at an existing foundry (e.g. AMI Semiconductor, 1.5 μm). The ultrasonic beam generator **48** and the ultrasonic echo detectors **50** are preferably microfabricated on the first integrated circuit **36** as capacitive micro-machined ultrasonic transducers (cMUT), similar in structure and function to devices disclosed by U.S. Pat. No. 6,246,158 (which is incorporated in its entirety by this reference), but differing significantly in structural materials and manufacturing method.

[**0037**] The mechanical structure of the cMUT device is preferably formed by layers deposited and patterned as part the foundry CMOS process itself (and preferably not augmented with additional steps for depositing material, aligning and patterning layers, and releasing/sealing diaphragms). The steps performed on the first integrated circuit **36** after the foundry fabrication preferably include only blanket etch and deposition steps, which require no alignment procedure or only rough alignment (with tolerances greater than 400 μm).

[**0038**] Preferably, the structure consists of a polysilicon lower electrode along with a dielectric membrane and metal upper electrode, with all layers integral to the CMOS process flow. In this case, a capacitive gap with a thickness of 0.5 μm to 1.2 μm is preferably formed between the membrane and the lower electrode by selectively etching a sacrificial metal layer (also integral to the CMOS process) that has been patterned to be exposed when the chip is immersed in a metal etch solution after completion of the foundry CMOS process. A vacuum-sealed cavity is preferably formed between the membrane and the lower electrode by sealing access ports to the gap using a low-temperature blanket dielectric deposition under vacuum (by PECVD and/or sputtering).

[**0039**] Alternatively, the structure may include a metal lower electrode and a dielectric membrane formed within the CMOS process flow. A gap is preferably formed between the dielectric membrane and the lower electrode by selectively etching a sacrificial metal layer (also integral to the CMOS process) that has been patterned to be exposed to attack when the chip is immersed in a metal etch solution after completion of the foundry CMOS process. In this case, vacuum sealing and the formation of the upper electrode, which is electrically common to all membranes on the chip, are accomplished by blanket depositions of metal and dielectric layers under vacuum (by PECVD and/or sputtering).

[**0040**] The second integrated circuit **38**, as shown in **FIG. 3**, of the handheld probe **14** functions to receive and transmit the beam signals from the probe receiver **34** to the beam signal leads **44** of the first integrated circuit **36**, and to receive and transmit the multiplexed echo signals from the echo signal leads **46** to the probe transmitter **40**. Preferably, the second integrated circuit **38** further conditions the multiplexed echo signals to facilitate wireless communication to the central console **12**. The conditioning may include converting the analog echo signals to adequately sampled (e.g. above Nyquist) digital signals, amplifying the analog echo signals, compressing the digital echo signals, and performing an error-correction process on the echo signals. The conditioning may further include additional multiplexing of the multiplexed echo signals into one channel (or simply less channels). Any number of multiplexing schemes may be used, including time-division multiplexing, code-division multiplexing, frequency-division multiplexing, packet-based transmission, or any other suitable multiplexing scheme. The second integrated circuit **38** preferably uses conventional devices and manufacturing methods, but may alternatively use any suitable device and any suitable manufacturing method.

[**0041**] In the preferred embodiment, the handheld probe **14** further provides time gain compensation of the echo signals, which corrects for attenuation and allows objects at a greater depth to be clearly depicted with objects of lesser depth. This function may be integrated onto the first integrated circuit **36**, the second integrated circuit **38**, or any other suitable locations within the handheld probe **14**. In alternative embodiments, the problem of attenuation may be solved with other suitable devices, either within the handheld probe **14**, the central console **12**, or any other suitable location.

[**0042**] In the preferred embodiment, the central console **12** transmits multiple beam signals as a single multiplexed beam signal. For this reason, the central console **12** preferably includes a multiplexer (not shown) and the handheld probe **14** includes a de-multiplexer (not shown). In alternative embodiments, the beam signals are sent using multiple channels or using another suitable scheme.

[**0043**] In the preferred embodiment, the handheld probe **14** further includes probe controls **58**, which function to provide additional interaction with the operator of the ultrasound system **10**. Like the console controls **18**, the probe controls **58** preferably allow the operator to configure the ultrasound system **10**, to switch between imaging modes, and to capture frame/cine. Because of the proximity to the subject **16**, however, the probe controls **58** may further include additional features, such as flag image, add caption or notation, add voice notation, and take measurement from image. The probe controls **58** may alternatively provide other appropriate functions. Input from the operator is collected, wirelessly transmitted to the central console **12**, and routed to the image processor **26** and/or the beam controller **20** as appropriate. The probe controls **58** may include knobs, dials, switches, buttons, touch pads, fingertip sensors, sliders, joysticks, keys, or any other appropriate device(s) to provide interaction with the operator. The handheld probe **14** with the probe controls **58** of the preferred embodiment satisfies the need to allow operation of an ultrasound system **10** during a patient examination without requiring physical proximity to the central console **12**.

[0044] In the preferred embodiment, the handheld probe **14** further includes a probe display **60**. In a first variation of the preferred embodiment, the console transmitter **22** and the probe receiver **34** are further adapted to communicate information about the system configuration (such as imaging modes). With this variation, the probe display **60** is preferably adapted to display the system configuration. In a second variation of the preferred embodiment, the console transmitter **22** and the probe receiver **34** are further adapted to communicate a processed image of the subject **16** (e.g., 3D, semi-transparent rendering, and 2D slices through the 3D structure). With this variation, the probe display **60** is preferably adapted to display the processed image. In a third variation, the console transmitter **22** and the probe receiver **34** are adapted to communicate both the information about the system configuration and the processed images. With this variation, the handheld probe **14** may include an additional probe display **60**, or may include a switch between the two sources. The probe display **60** preferably includes a conventional LCD screen, but may alternatively include any appropriate device such as individual lights, digital displays, alphanumeric displays, or other suitable indicators. With the probe controls **58** and the probe display **60**, the handheld probe **14** of the preferred embodiment further exceeds the need to allow operation of an ultrasound system **10** during a patient examination without requiring physical proximity to the central console **12**.

[0045] In the preferred embodiment, the handheld probe **14** further includes a power source **62**, which functions to power the components of the handheld probe **14**. The power source **62** is preferably a conventional rechargeable battery, but may alternatively be a capacitor, a fuel cell, or any other suitable power source **62**. Considering the state of battery technology, however, it is possible that the addition of a power source **62** would make the handheld probe **14** unacceptably heavy or bulky. Thus, in a variation of the preferred embodiment shown in **FIG. 8**, the power source **62** is located in a remote portion **64** of the handheld probe **14**, which is connected to the handheld probe **14** with a lightweight cord **66**. The remote portion **64** may be designed to be strapped to the operator's body (e.g., wrist, arm, or shoulder) or clipped to the operator's belt, with the cable routed such that it is kept conveniently out of the way (e.g., along the arm). Although this variation still requires a cable connected to the handheld probe **14**, the cable moves with the operator and thus provides a degree of freedom that is still greater than a transducer head tethered to the central console. Further, in the variation of the preferred embodiment, other elements of the handheld probe **14** may be located in the remote portion **64**. For example, the probe receiver, the probe transmitter, the probe controls, and/or the probe display may be located in the remote portion **64** of the handheld probe **14**.

[0046] As a person skilled in the art of ultrasound systems will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the preferred embodiment of the invention without departing from the scope of this invention defined in the following claims.

We claim:

1. A single integrated circuit for a handheld probe of an ultrasound system, comprising:

a two-dimensional array of at least 512 transducer cells, each transducer cell adapted to receive a beam signal, generate an ultrasonic beam, detect an ultrasonic echo at multiple locations, and combine the ultrasonic echoes into a single multiplexed echo signal, wherein each transducer cell includes at least one ultrasonic beam generator and at least four ultrasonic echo detectors;

a series of beam signal leads adapted to carry the beam signals to the transducer cells; and

a series of echo signal leads adapted to carry the multiplexed echo signals from the transducer cells.

2. The integrated circuit of claim 1, wherein the two-dimensional array includes at least 1024 transducer cells, and wherein each transducer cell includes at least fifteen ultrasonic echo detectors.

3. The integrated circuit of claim 1, wherein the ultrasonic beam generator is a separate element from the at least four ultrasonic echo detectors.

4. The integrated circuit of claim 3, wherein the ultrasonic beam generator and the at least four ultrasonic echo detectors are each an ultrasonic transducer capable of both generating an ultrasonic beam and detecting an ultrasonic echo.

5. The integrated circuit of claim 4, wherein the ultrasonic beam generator is capable of generating an ultrasonic beam with a higher output than one of the ultrasonic echo detectors.

6. The integrated circuit of claim 5, wherein one of the ultrasonic echo detectors is capable of detecting an ultrasonic echo with greater sensitivity than the ultrasonic beam generator.

7. The integrated circuit of claim 3, wherein the ultrasonic beam generator and the at least four ultrasonic echo detectors differ by at least one characteristic from a group consisting of diaphragm diameter, thickness, tensile stress, gap spacing, control electronics, and electrode configuration.

8. The integrated circuit of claim 1, wherein the ultrasound beam generators are arranged in a substantially regular hexagonal tessellation.

9. The integrated circuit of claim 7, wherein each ultrasound beam generator is arranged in the center of the transducer cell.

10. The integrated circuit of claim 1, wherein each transducer cell includes a multiplexer adapted to combine at least a portion of the ultrasonic echoes into a single multiplexed echo signal.

11. A handheld probe for an ultrasound system, comprising:

a probe receiver adapted to wirelessly receive beam signals;

the first integrated circuit of claim 1;

a second integrated circuit including a multiplexer connected to the series of echo signal leads and adapted to combine the multiplexed echo signals; and

a probe transmitter connected to the multiplexer and adapted to wirelessly transmit a multiplexed echo signal.

12. The handheld probe of claim 11 further comprising a display.

13. The handheld probe of claim 11, wherein the two-dimensional array includes at least 1024 transducer cells, and wherein each transducer cell includes at least fifteen ultrasonic echo detectors.

14. An ultrasound system, comprising:

a central console including a controller adapted to create beam signals; a console transmitter connected to the controller and adapted to wirelessly transmit the beam signals; and

the handheld probe of claim 11;

wherein the central console further includes a console receiver adapted to wirelessly receive a multiplexed echo signal; and an image processor adapted to construct an image from the echo signals.

15. The ultrasound system of claim 14 further comprising a display.

16. The ultrasound system of claim 14, wherein the two-dimensional array includes at least 1024 transducer cells, and wherein each transducer cell includes at least fifteen ultrasonic echo detectors.

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专利名称(译)	用于超声系统的集成电路		
公开(公告)号	US20060058667A1	公开(公告)日	2006-03-16
申请号	US11/229197	申请日	2005-09-15
[标]申请(专利权)人(译)	LEMMERHIRT DAVID°F RICH COLLIN A MARTIN史蒂芬中号 SCHOX JEFFREY中号		
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IPC分类号	A61B8/14		
CPC分类号	A61B8/00 A61B8/483 A61B8/4472 A61B8/4483		
优先权	60/610337 2004-09-15 US 60/610319 2004-09-15 US 60/610320 2004-09-15 US		
外部链接	Espacenet USPTO		

摘要(译)

本发明的优选实施例包括用于超声系统的手持式探头的单个集成电路。集成电路包括至少512个换能器单元的二维阵列，每个换能器单元适于接收波束信号，产生超声波束，检测多个位置处的超声回波，并将超声回波组合成单个多路回波。信号。每个换能器单元包括至少一个超声波束发生器和至少四个超声回波检测器。该集成电路还包括一系列适于将波束信号传送到换能器单元的波束信号引线和一系列适于承载来自换能器单元的多路复用回波信号的回波信号引线。