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(54) **ULTRASOUND TRANSDUCER**

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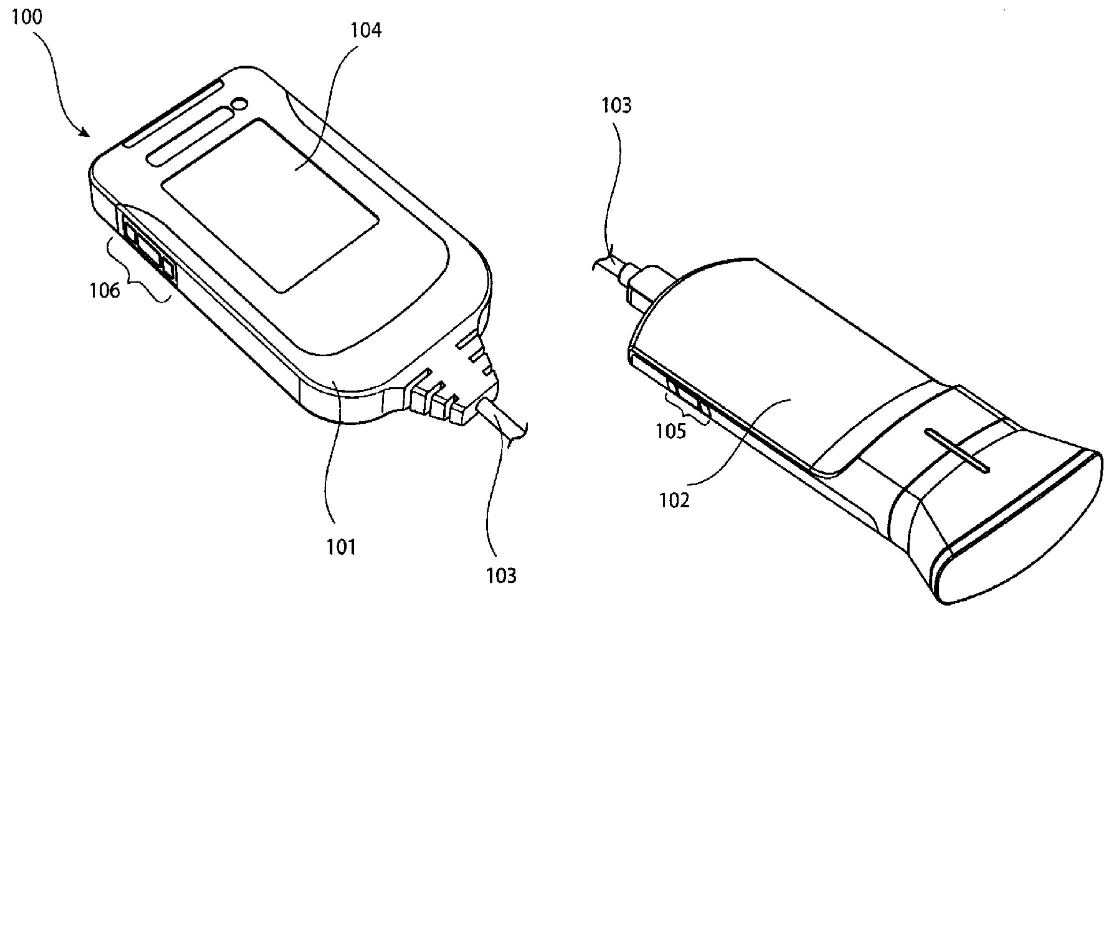
(57) **ABSTRACT**

An ultrasound system having a transducer probe unit including at least one transducer for transmitting and receiving ultrasonic signals, wherein the transducer is moved with respect to the probe unit in a repetitive motion by an ultrasonic motor.



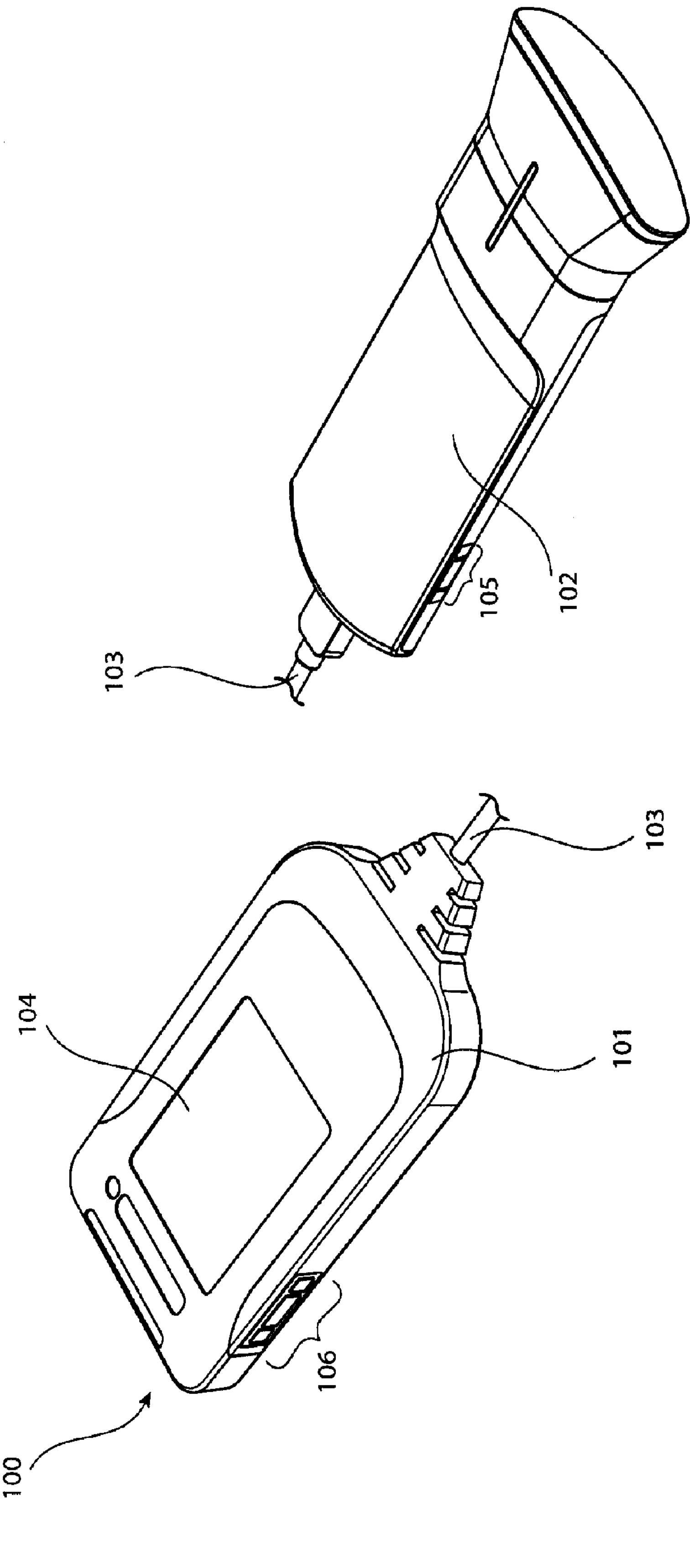
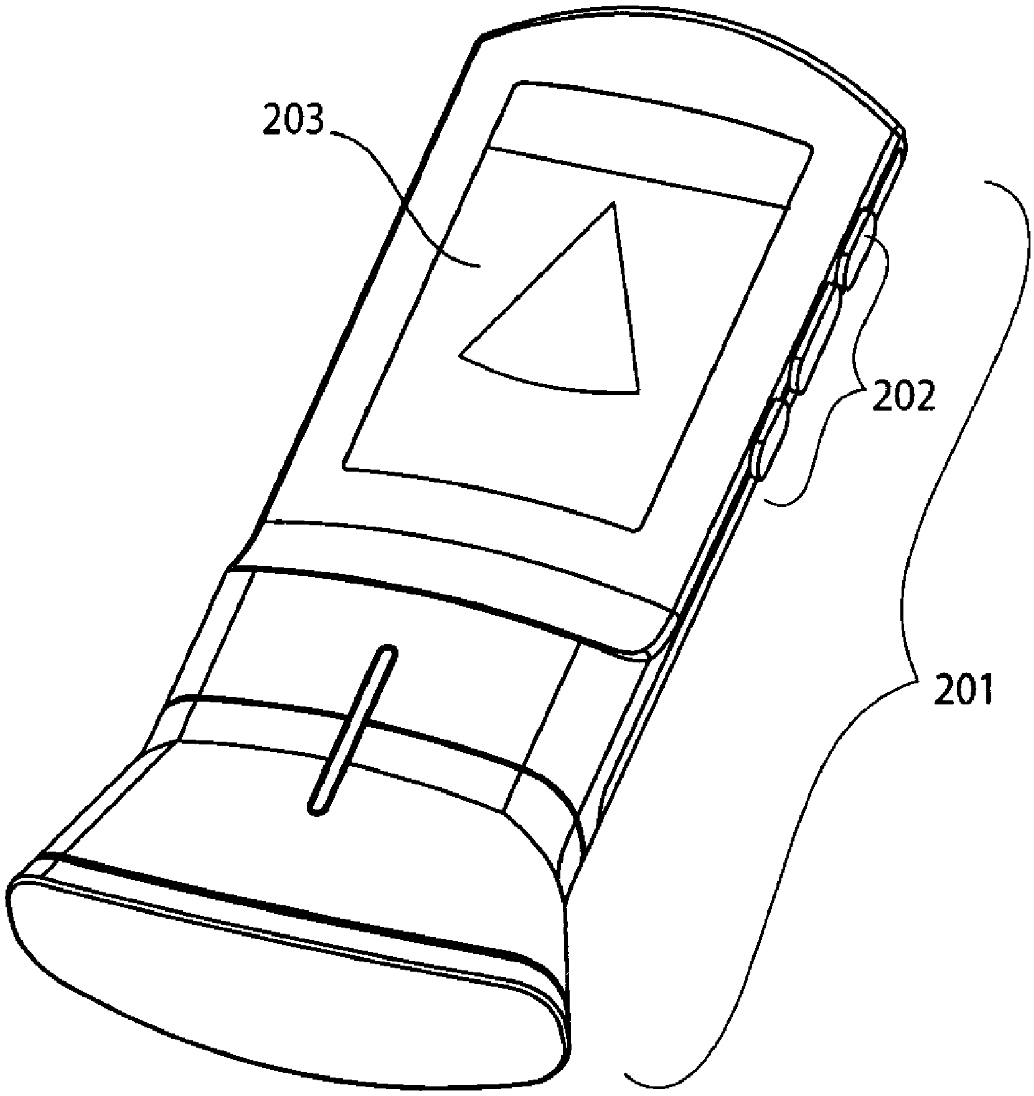


Figure 1



Fiaure 2

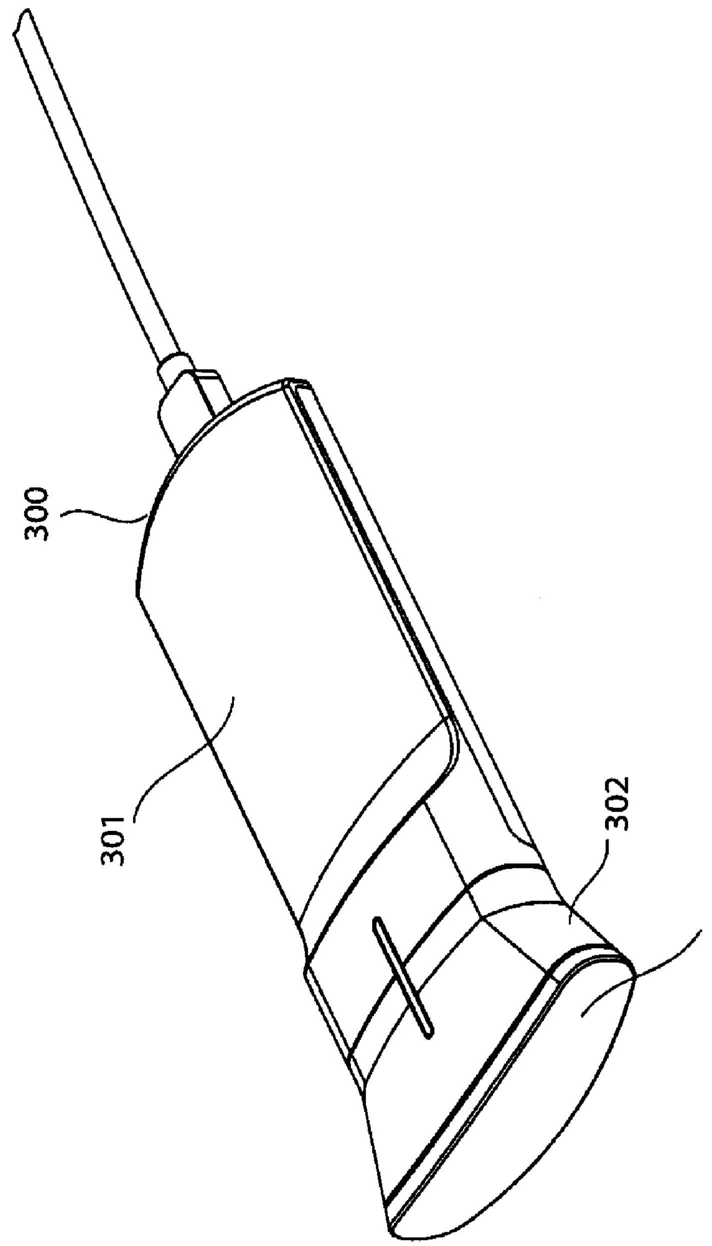


Figure 3

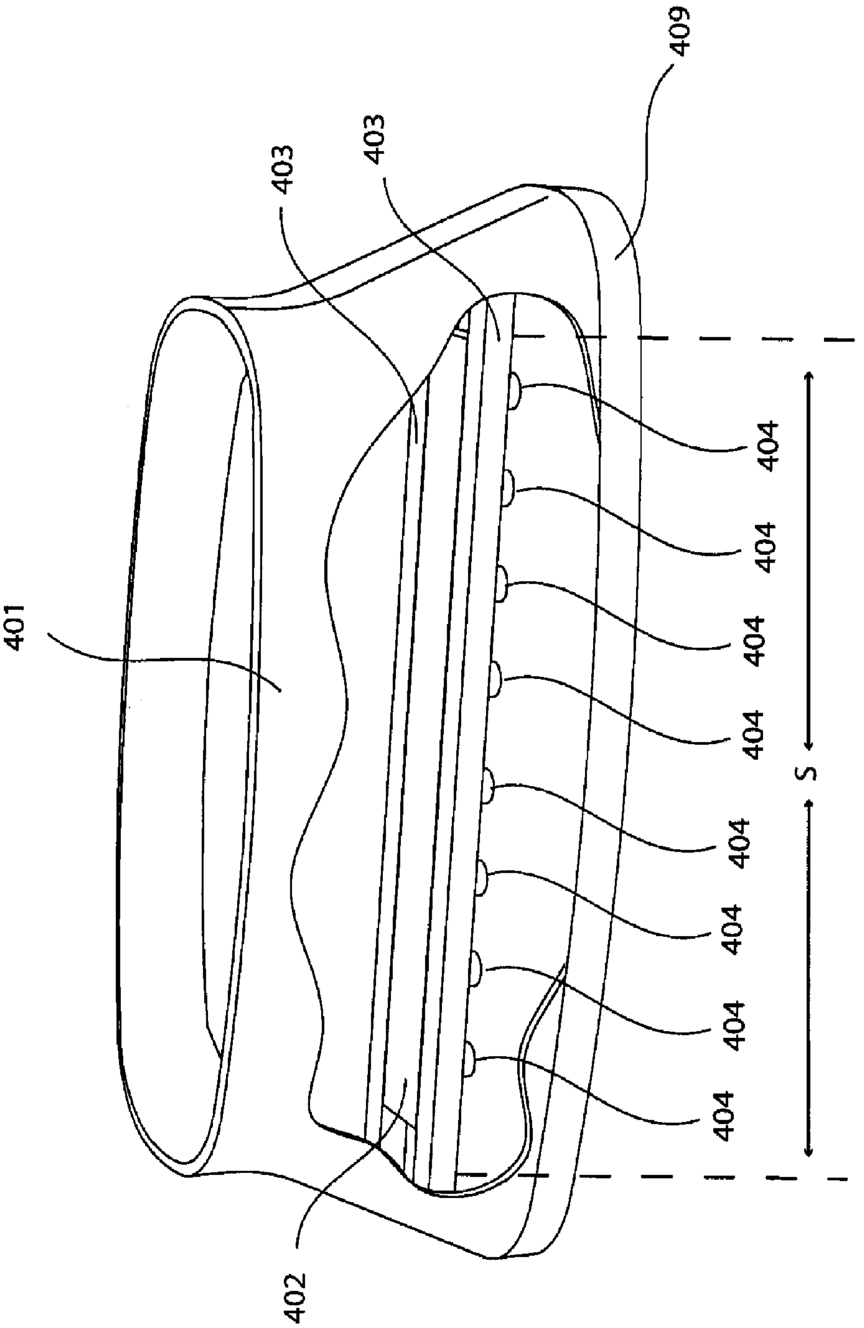


Figure 4

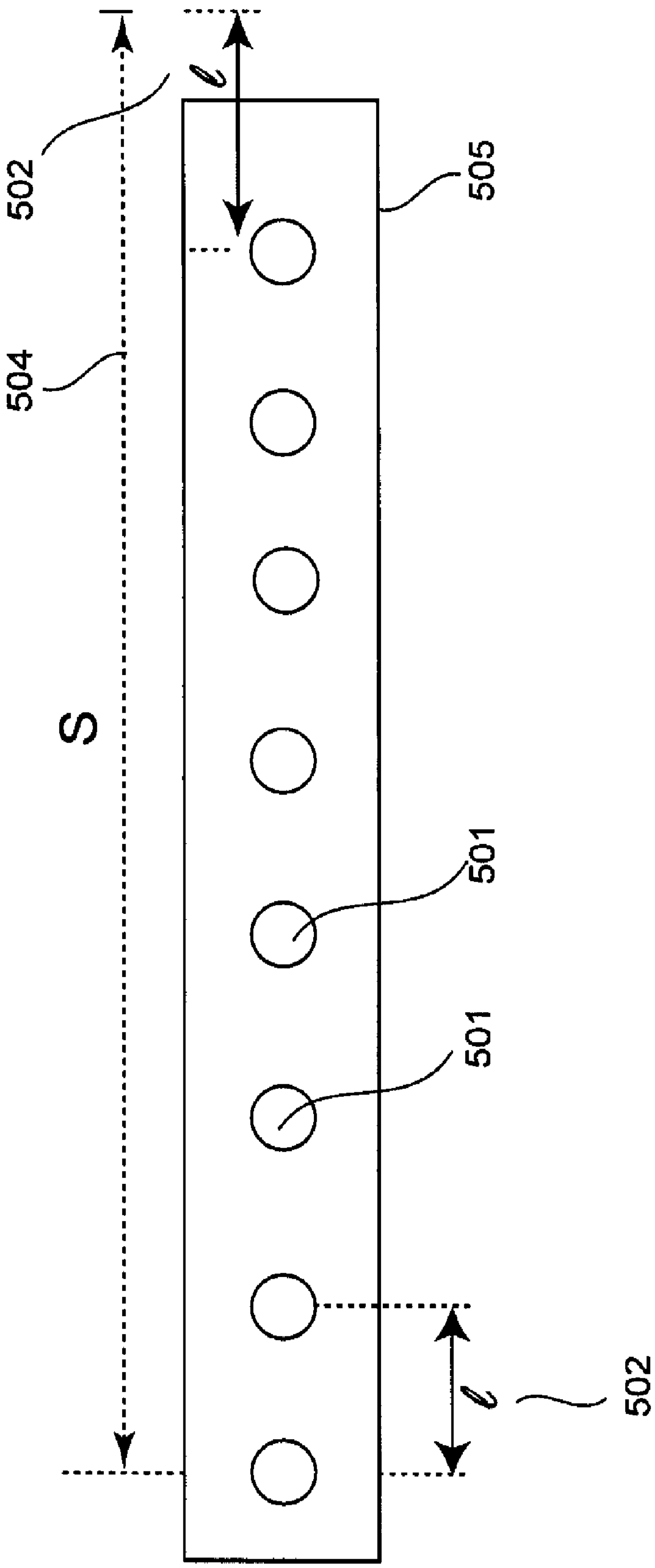


Figure 5

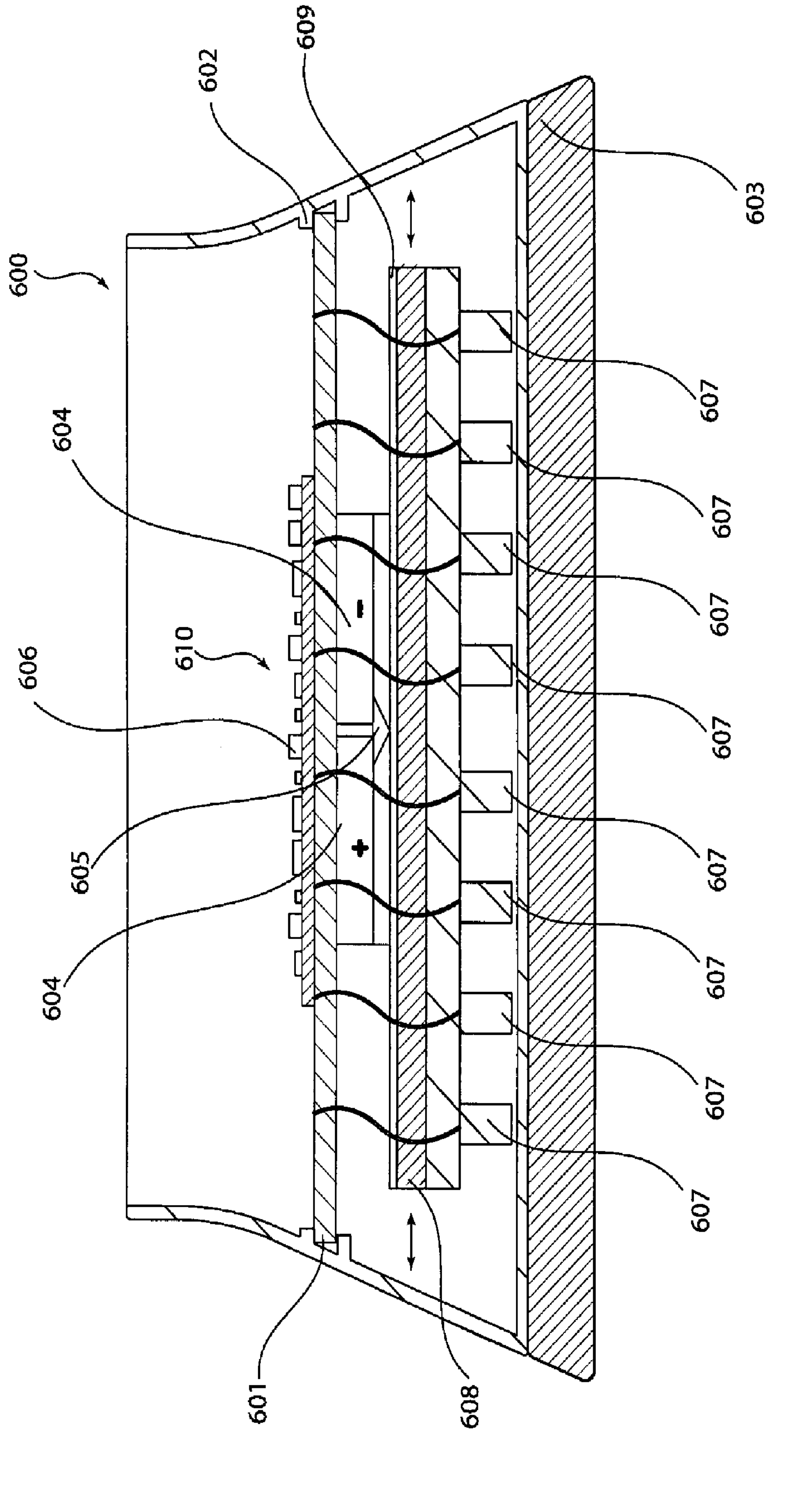


Figure 6

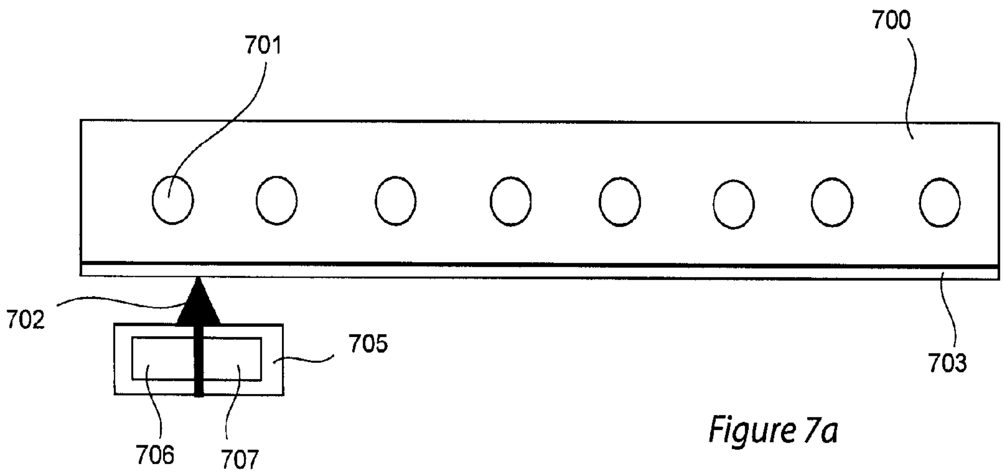


Figure 7a

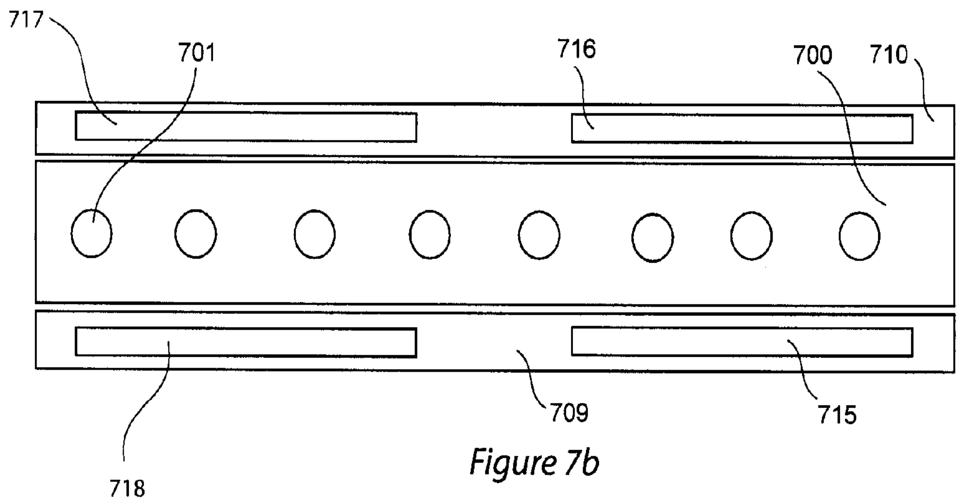


Figure 7b

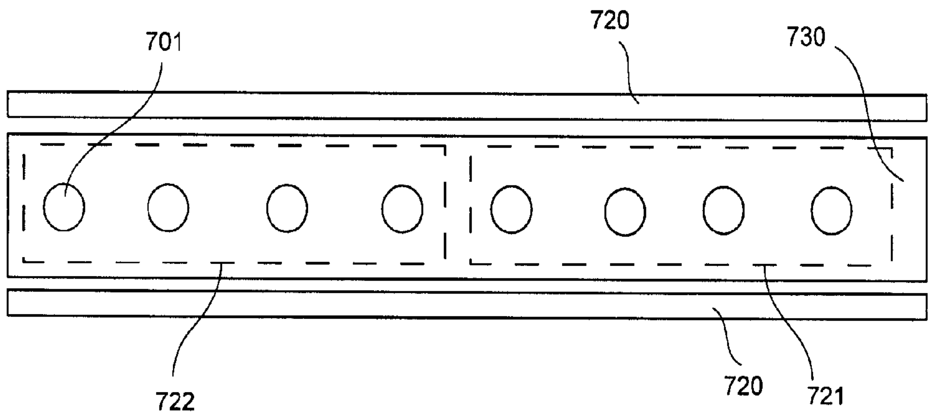


Figure 7c

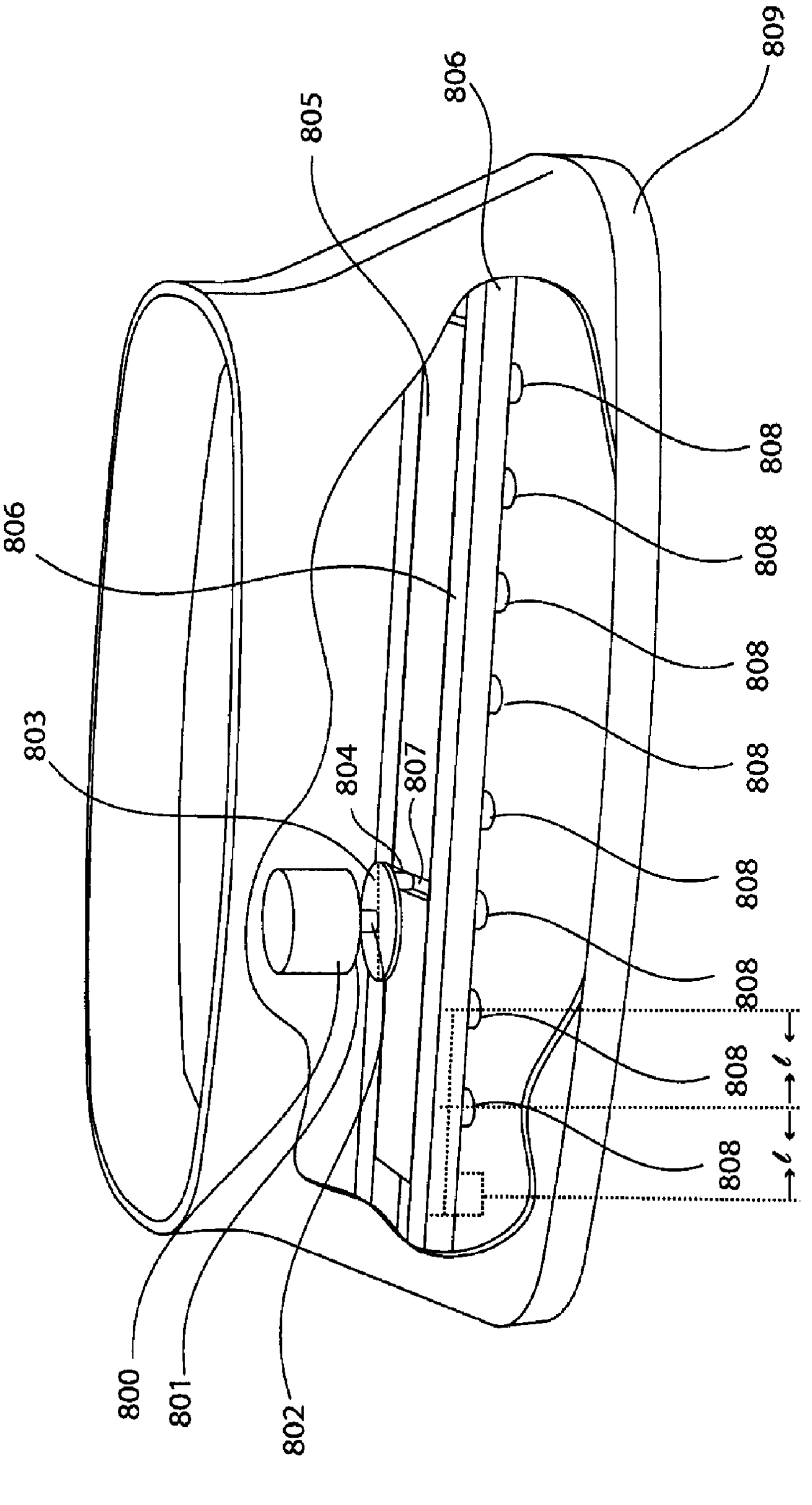

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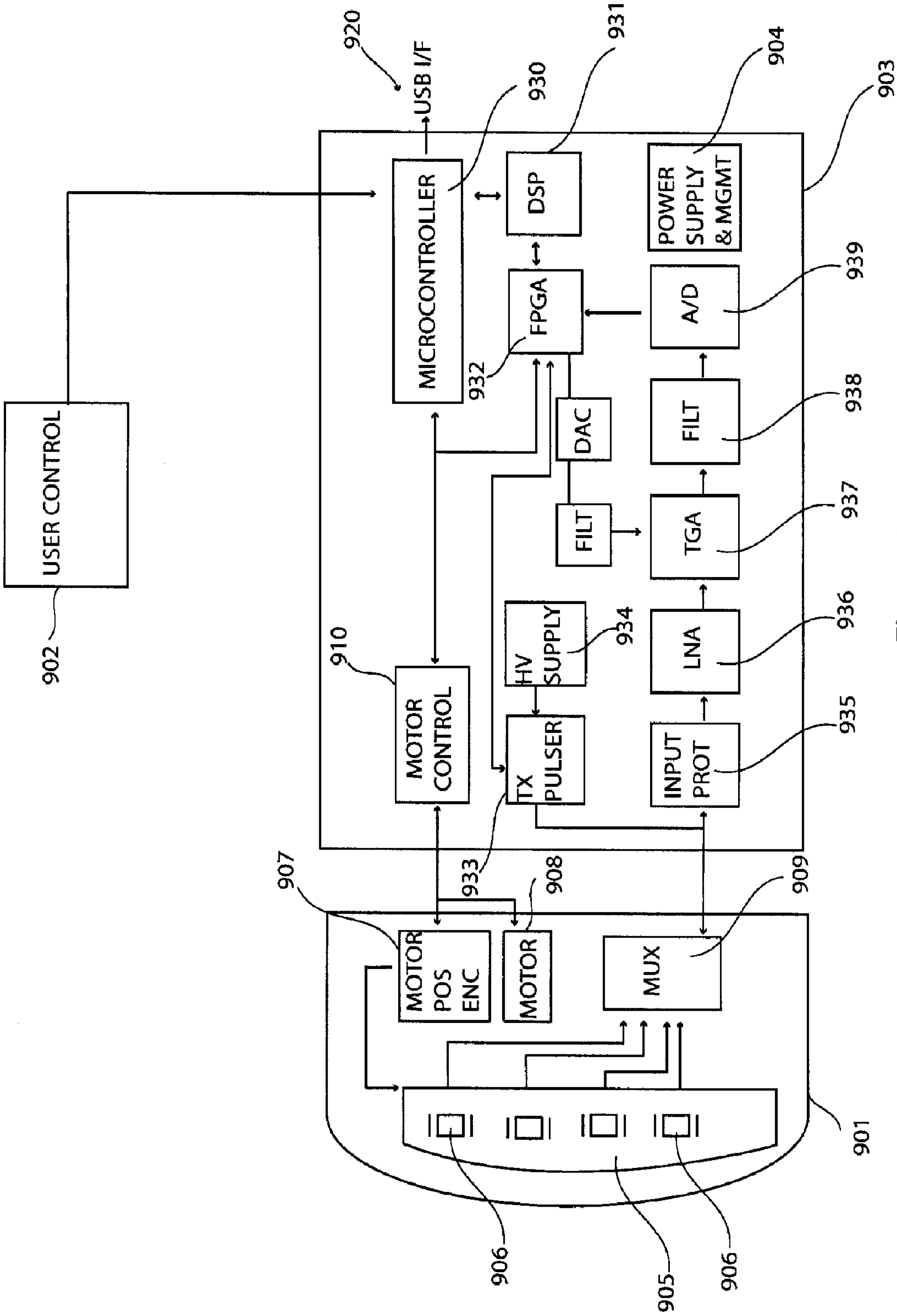
Figure 8


USER CONTROL
902
920
USB I/F
930
931
904
903
MICROCONTROLLER
DSP
POWER SUPPLY & MGMT
FPGA
932
A/D
939
DAC
FILT
938
FILT
TGA
937
910
MOTOR CONTROL
HV SUPPLY
934
LNA
936
TX PULSER
933
INPUT PROT
935
907
908
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MOTOR POS ENC
MOTOR
MUX
901
906
905
906

Figure 9

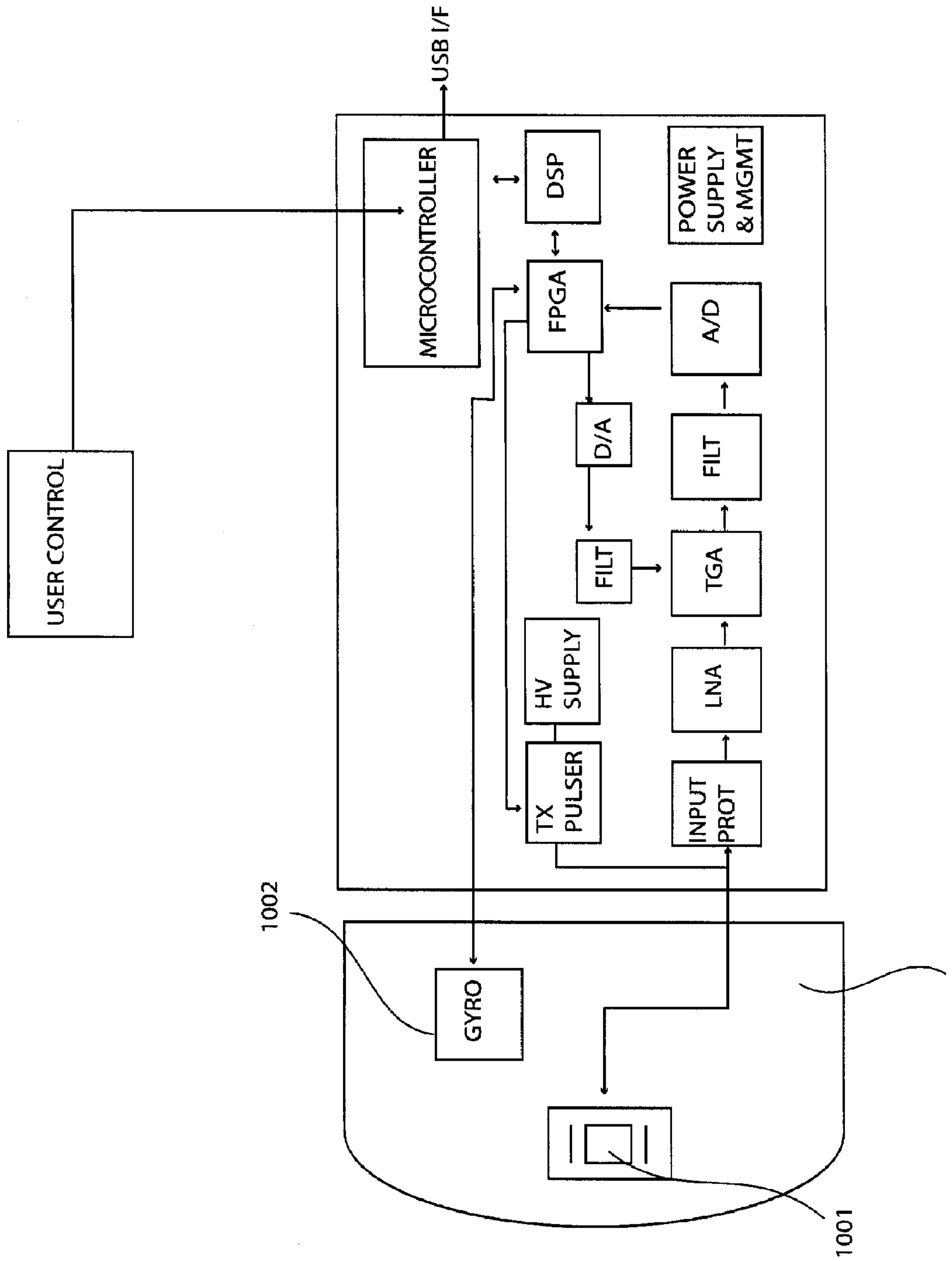
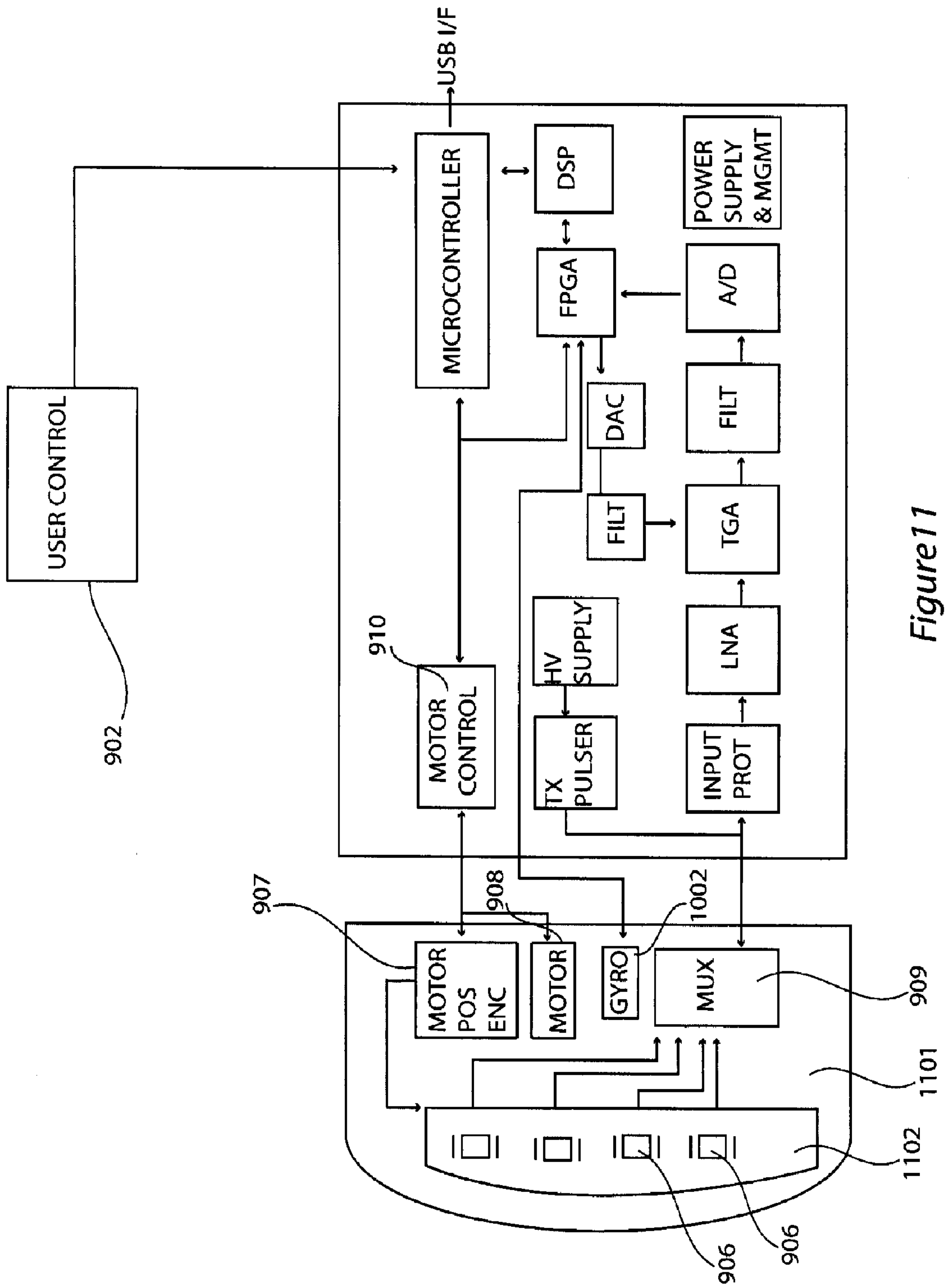

USB I/F
MICROCONTROLLER
DSP
POWER SUPPLY & MGMT
FPGA
A/D
D/A
FILT
FILT
TGA
USER CONTROL
HV SUPPLY
LNA
TX PULSER
INPUT PROT
1002
GYRO
1003
1001

Figure 10


USB I/F
USER CONTROL
902
MICROCONTROLLER
DSP
POWER SUPPLY & MGMT
FPGA
A/D
DAC
FILT
FILT
TGA
LNA
HV SUPPLY
TX PULSER
INPUT PROT
MOTOR CONTROL
910
907
908
1002
MOTOR POS ENC
MOTOR
GYRO
MUX
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1101
1102
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906

Figure11

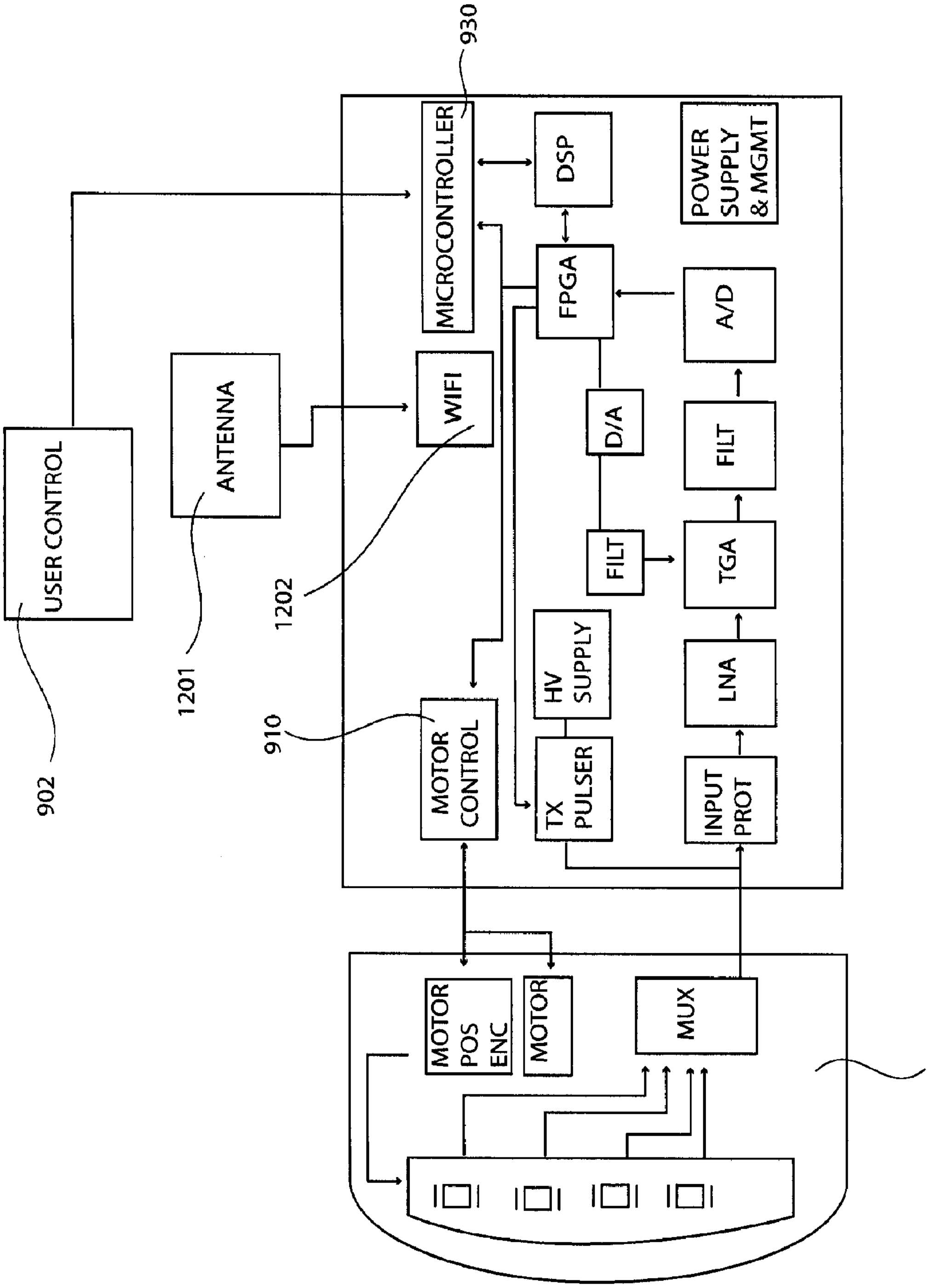
930
MICROCONTROLLER
DSP
POWER SUPPLY & MGMT
FPGA
A/D
WIFI
ANTENNA
USER CONTROL
D/A
FILT
FILT
TGA
HV SUPPLY
LNA
1202
1201
902
910
MOTOR CONTROL
TX PULSER
INPUT PROT
MOTOR POS ENC
MOTOR
MUX
901

Figure 12

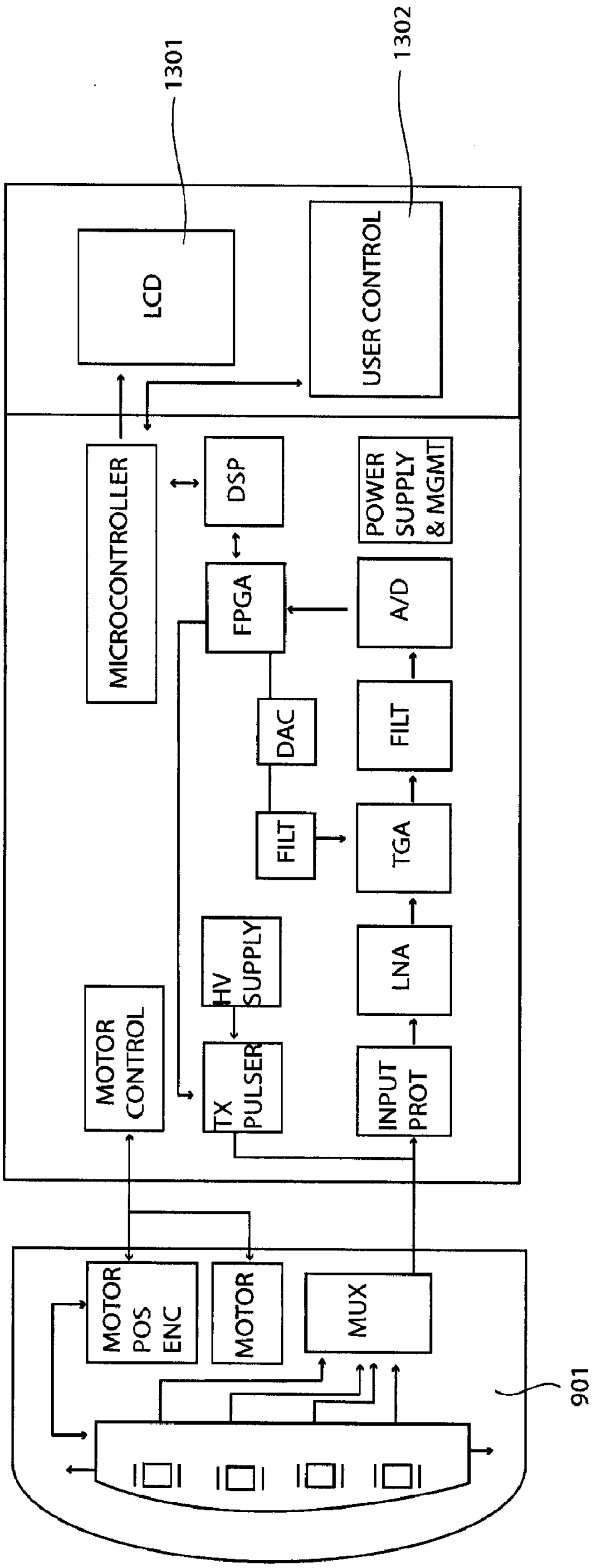
1301
1302
LCD
USER CONTROL
MICROCONTROLLER
DSP
POWER SUPPLY & MGMT
FPGA
A/D
DAC
FILT
FILT
TGA
HV SUPPLY
LNA
MOTOR CONTROL
TX PULSER
INPUT PROT
MOTOR POS ENC
MOTOR
MUX
901

Figure 13

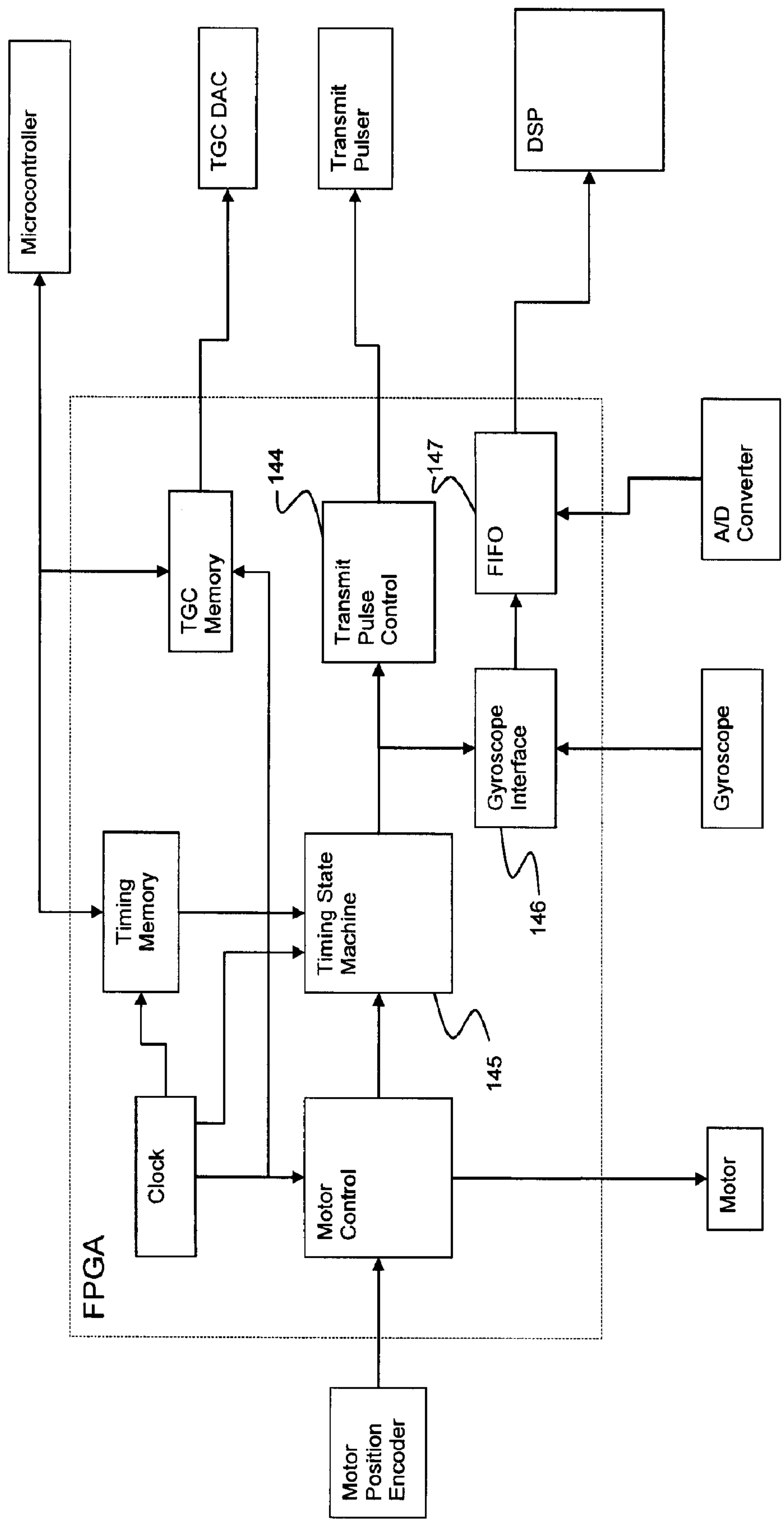
Microcontroller
TGC DAC
Transmit Pulser
DSP
FPGA
TGC Memory
144
Transmit Pulse Control
147
FIFO
A/D Converter
Timing Memory
Timing State Machine
Gyroscope Interface
Gyroscope
146
145
Clock
Motor Control
Motor
Motor Position Encoder

Figure 14

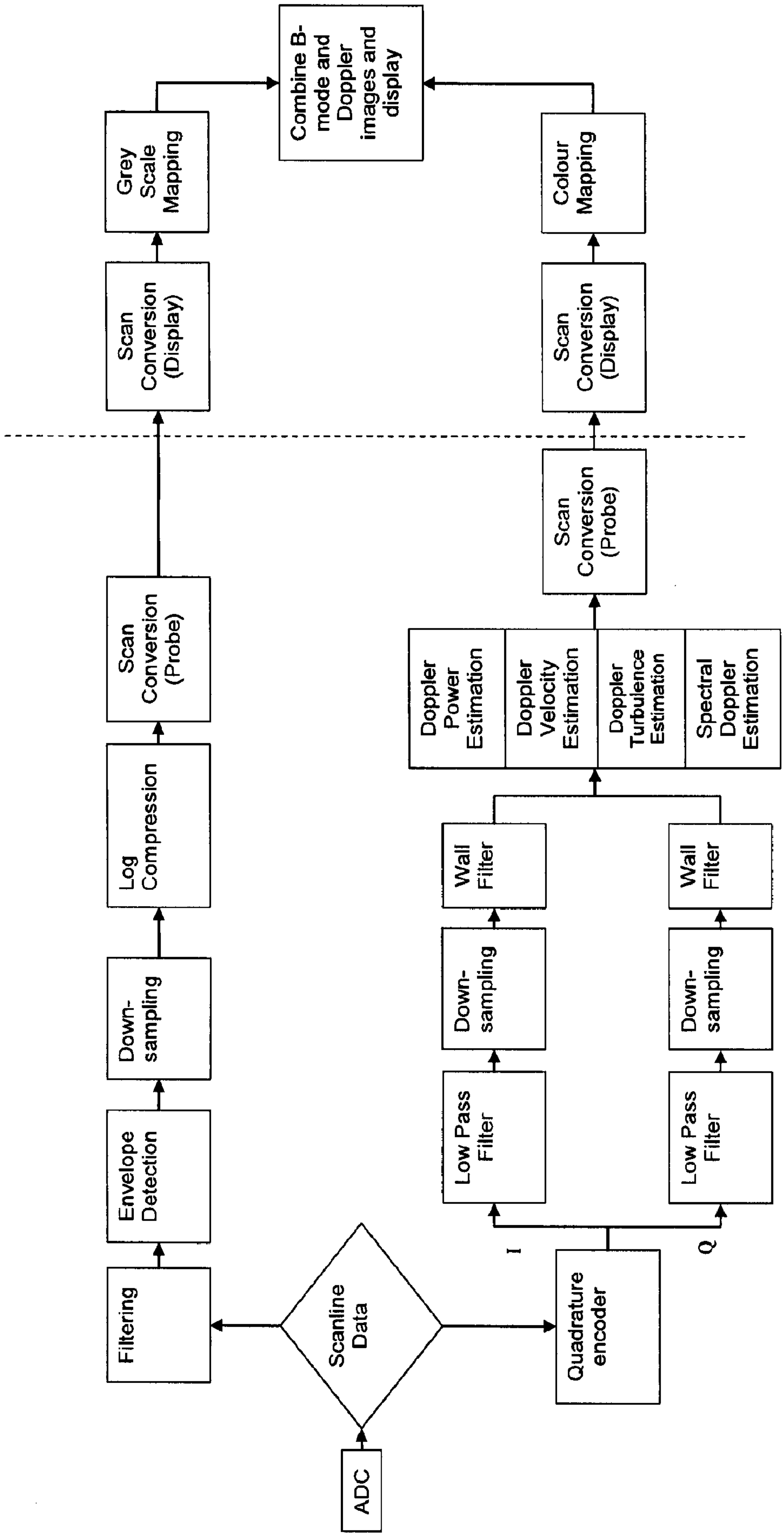
ADC
Scanline Data
Filtering
Envelope Detection
Down-sampling
Log Compression
Scan Conversion (Probe)
Scan Conversion (Display)
Grey Scale Mapping
Combine B-mode and Doppler images and display
Quadrature encoder
I
Q
Low Pass Filter
Down-sampling
Wall Filter
Low Pass Filter
Down-sampling
Wall Filter
Doppler Power Estimation
Doppler Velocity Estimation
Doppler Turbulence Estimation
Spectral Doppler Estimation
Scan Conversion (Probe)
Scan Conversion (Display)
Colour Mapping

Figure 15

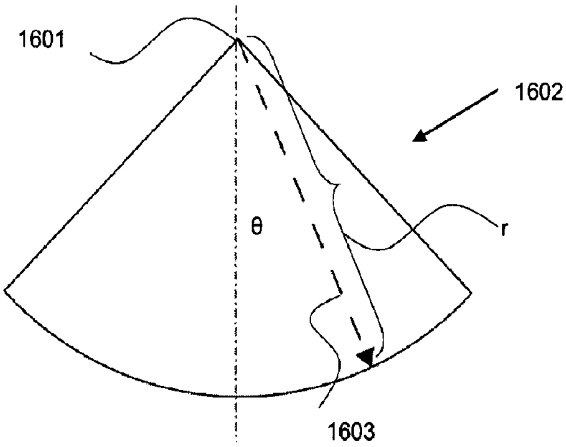

Figure 16a

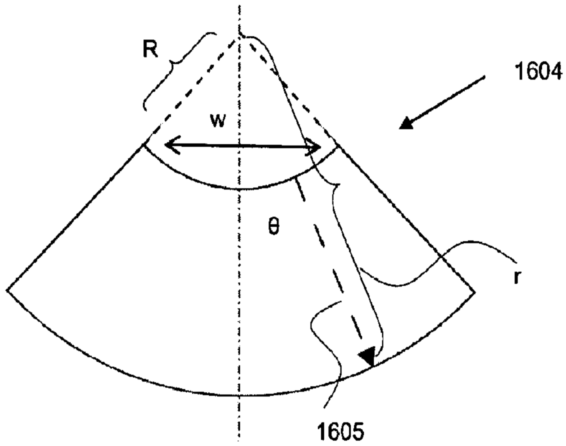

Figure 16b

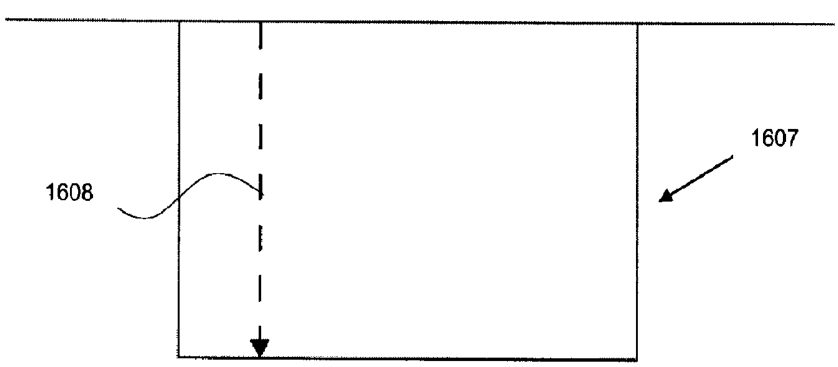

Figure 16c

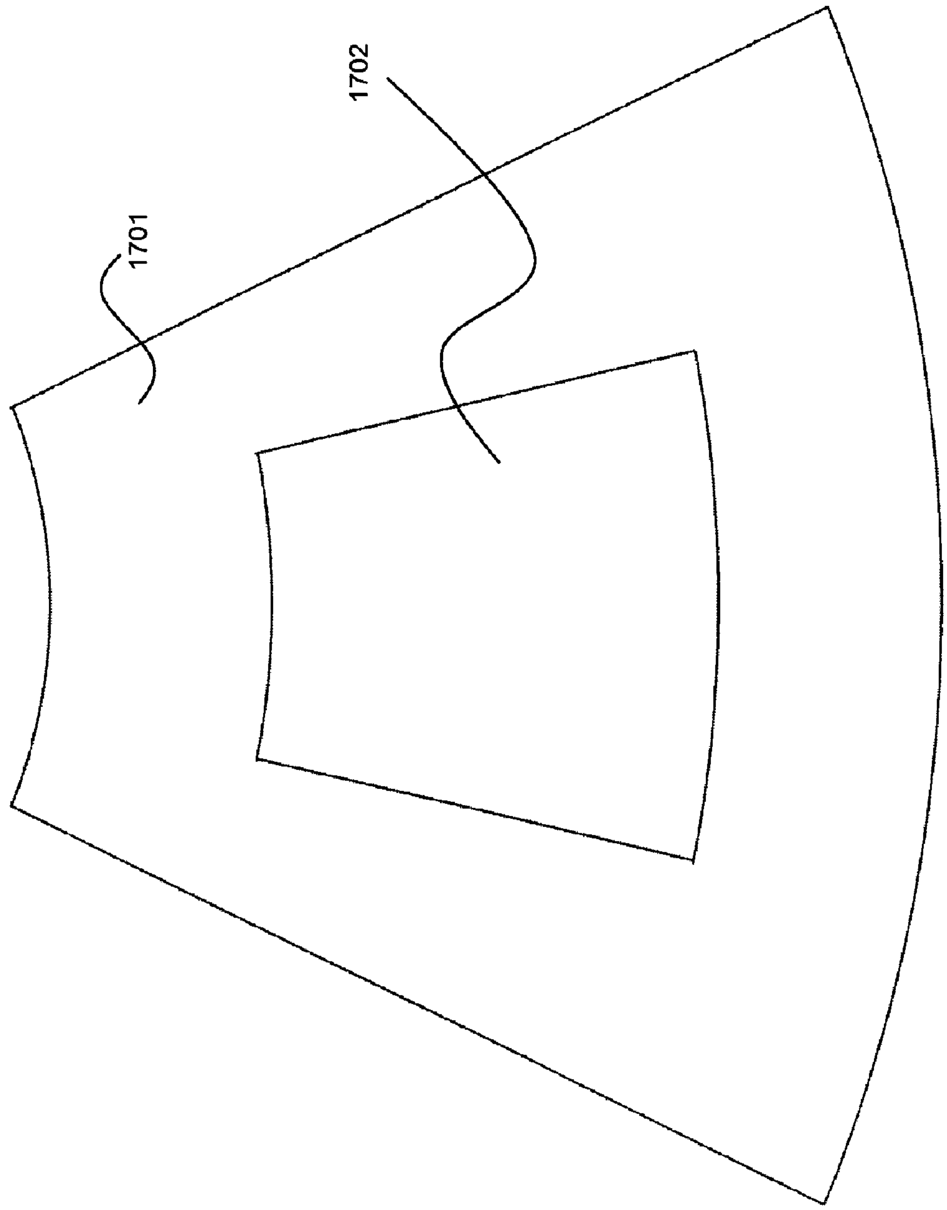

Figure 17

ULTRASOUND TRANSDUCER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 USC §119 (a) to Australian Provisional Application 2009902886 filed Jun. 23, 2009, the entirety of which is incorporated by reference herein.

TECHNICAL FIELD

[0002] The present invention relates to a real time medical ultrasound imaging system. In particular it relates to such a system employing a motor driven array.

BACKGROUND ART

[0003] Ultrasound is a non invasive technique for generating image scans of interior body organs. There are a number of types of real time ultrasound systems supporting a wide variety of ultrasound transducers. These systems can be divided into electronic systems such as phased array, curvilinear array, and linear array transducers which employ fully electronic techniques for beam forming and for directing the ultrasonic beam; and mechanical systems where a transducer or a transducer array is moved mechanically to direct the beam.

[0004] Mechanical scanners are traditionally the simplest and least expensive types of real time imaging systems. These systems utilize one or more piezoelectric crystals which transmit the sensing ultrasound signal, and receive the echoes returned from the body being imaged. To be effective, the ultrasound signal has significant directionality and may be described as an ultrasound beam. An electromagnetic motor is employed to move the crystal in a repetitive manner in order for the beam to cover an area to be imaged. The motor may be of any type, depending upon the movement characteristics required. Devices using stepping motors, DC motors and linear motors are known.

[0005] In general, mechanical ultrasound scanners employ one of two techniques for moving the beam and generating an image.

[0006] The first technique is the rotating wheel transducer where one or more crystals are rotated through 360° such that a beam emitted from the crystal would sweep out a circle. A sector of that circle constitutes the area to be imaged. The ultrasound signal is only transmitted and received while that sector is being swept out.

[0007] The second type of mechanical ultrasound scanner employs an oscillating transducer where a single crystal is moved back and forth by an electromagnetic motor such that the ultrasound beam emitted by the transducer sweeps out the region of interest.

[0008] Electromagnetic motors were invented more than a hundred years ago. These motors still dominate the industry, but must be considered to be at the limits of technological development. Performance improvements in mechanically driven ultrasound scanners cannot be expected from incremental improvements in such motors. Conventional electromagnetic motors are difficult to produce at the very small sizes which are desirable for use in a portable ultrasound probe.

[0009] Electromagnetic motors are very hard to control with precision and have low position resolution. They are also characterized by high speed and low torque and have a slow response.

[0010] The limitations in electromagnetic motors cause a number of problems with the current single crystal mechanical transducers.

[0011] Such transducers are prone to registration artifacts which are spurious apparent reflections which occur because the motor is free running, and hence image frames produced from consecutive sweeps may not exactly align. This may also result in image jitter which can make the images tiresome or fatiguing to view.

[0012] The motor is noisy and imparts a vibration to the ultrasound probe which is in contact with the patient. This may be disconcerting or uncomfortable for the patient.

[0013] In addition any form of Doppler imaging is not possible due to wobble and positional error in the motor.

[0014] Electronic systems which do not use motors, including phased array, curvilinear, and linear transducers overcome many of the problems with mechanical systems, including image registration, ability to perform Doppler imaging, vibration and noise. However, electronic systems have other shortcomings. They are more expensive to manufacture, have relatively high power consumption, and are relatively larger because, to achieve satisfactory performance, they include a large number of transducer elements and associated electronic channels.

SUMMARY OF THE INVENTION

[0015] In one form of this invention there is proposed an ultrasound transducer probe unit of a type including a body portion and at least one transducer for transmitting and receiving ultrasonic signals, the transducer being mechanically moved with respect to the body portion in a repetitive motion in order to insonify an area, wherein the movement of the transducer is able to be controlled to return to a selected position relative to the body portion with an error of less than 100 micro meters.

[0016] Ultrasonic motors are very precise in movement and can be positioned to nanometer accuracy. Ultrasonic motors have excellent response time and hence can be moved and stopped very quickly.

[0017] In a further preferred form, the invention may be said to lie in an ultrasound transducer probe unit including a body portion and at least one transducer for transmitting and receiving ultrasonic signals, wherein the transducer is moved with respect to the body portion in a repetitive motion by an ultrasonic motor.

[0018] Ultrasound Doppler analysis gives information about the movement of elements, usually blood, within the body being imaged. Useful information cannot be obtained if the transducer is itself moving with the vibration of a driving electromagnetic motor. Doppler information is extracted from multiple scanlines. It is thus necessary that repeated scanlines be able to be obtained from precisely the same area of the body.

[0019] In preference, the probe unit is adapted to produce scanline data suitable for processing to enable display of at least one of gated Doppler, power Doppler, Pulse Wave Doppler, color Doppler, and Duplex Doppler information.

[0020] In a further preferred form the invention may be said to lie in an ultrasound transducer probe unit including an ultrasound transducer unit having an array of transducers wherein the transducer unit is adapted to be moved in a reciprocating motion a selected linear distance along a linear axis, the linear separation between the transducers along the linear axis being of a similar magnitude to the linear distance, the transducer unit being adapted to be operated to acquire scanlines during each reciprocation.

[0021] In preference, the reciprocating motion consists of discrete steps, with a scanline being acquired only when the transducer is stationary.

[0022] In preference, the transducer movement is driven by a linear ultrasonic motor.

[0023] In the alternative, the transducer movement is driven by a rotary ultrasonic motor.

[0024] In a further form the invention may be said to lie in a method of ultrasound scanning whereby there is provided an array of at least one ultrasound transducers, the transducers being moved in a repetitive motion with respect to a body to be imaged by an ultrasonic motor, an ultrasound image being produced for display, the image comprising scanlines acquired by the transducers at consecutive points along the path of the movement, with each transducer contributing scanlines to the image.

[0025] In preference the method further includes the steps of a user selecting an area of the image as a Doppler window; the transducer being moved and acquiring image scanlines, the transducer being controlled to stop at a stop position such that a scanline acquired by the transducer will fall into the Doppler window, the transducer acquiring scanlines for Doppler processing at the stop position, the transducer being again moved and acquiring scanlines, the transducer being returned to the stop position and acquiring a further scanlines for Doppler processing, the return to the stop position being done with an accuracy sufficient to allow for continuing Doppler imaging, the scanlines being processed to provide a display to a user of an ultrasound image with Doppler information. 3D volume imaging may also be performed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. **1** shows an exemplary ultrasound scanning apparatus incorporating the invention having a separate host display unit.

[0027] FIG. **2** shows an exemplary ultrasound scanning apparatus incorporating the invention where the scanning and control units are integrated.

[0028] FIG. **3** shows a probe unit of the scanning apparatus of FIG. **1**.

[0029] FIG. **4** shows a cross section of an ultrasound probe unit scan head incorporating an ultrasonic linear motor.

[0030] FIG. **5** shows a transducer slider of the scan head of FIG. **4**.

[0031] FIG. **6** is a cross-section view of an alternative scan head version.

[0032] FIG. **7** shows three possible alternative versions for the transducer array slider for any version of the invention.

[0033] FIG. **8** shows cross section of an ultrasound probe unit scan head incorporating a rotary motor.

[0034] FIG. **9** shows a system block diagram of an ultrasound probe unit scan head having a curvilinear shaped transducer and including a USB interface connection to a host display.

[0035] FIG. **10** shows a system block diagram of an ultrasound probe unit scan head having a single channel ultrasound element and including a USB interface connection to a host display.

[0036] FIG. **11** shows a system block diagram of an ultrasound probe unit scan head having a curvilinear shaped transducer and including a gyroscope and a USB interface connection to a host display.

[0037] FIG. **12** shows a system block diagram of an alternative version of the ultrasound probe unit scan head including a wireless interface to a host display.

[0038] FIG. **13** shows a system block diagram of an ultrasound probe unit scan head having an integrated display.

[0039] FIG. **14** is a block diagram of an FPGA timing and control unit of the system of FIG. **1**.

[0040] FIG. **15** is a block diagram of the DSP software of the system of FIG. **1**.

[0041] FIGS. **16***a*, **16***b*, and **16***c* illustrate the scan conversion requirements for different transducer shapes which may be incorporated in apparatus of the present invention.

[0042] FIG. **17** illustrates a Doppler processing window.

DETAILED DESCRIPTION OF PREFERRED VERSIONS OF THE INVENTION

[0043] Now referring to the illustrations, and in particular to FIG. **1**, there is shown a view of an exemplary ultrasound scan apparatus **100**. This includes a display unit **101**, and a probe unit **102**. These are connected by communications cable **103**. The display unit has a display **104**. The display screen may be a touch screen allowing a user to control the functionality of the display unit and the probe unit. In the illustrated version, control members **106** are provided on the display unit, in the form of push buttons and a scrollwheel. Control members **105** are provided on the probe unit. Either or both of these control members may be absent.

[0044] FIG. **2** shows an alternative version where the features of the display unit are incorporated in the probe unit **201**. There is a display **203** included in the probe unit. This may be a touchscreen and provide a user interface to control the function of the ultrasound scan apparatus. There may be provided control members **202** on the probe unit for access to a user interface to control the ultrasound scan apparatus.

[0045] FIG. **3** shows a probe unit **300** which has a body **301**. The body **301** is connected to a probe unit scan head **302**. The scan head **302** includes a transducer which may be, without limitation, an array transducer having multiple transducer elements, a single element transducer or an array of separate, individual transducers.

[0046] The scan head **302** includes a front panel **303** which contacts the patient during scanning. This front panel is acoustically transparent. It is desirable to provide the best possible acoustic coupling between the transducer elements and the body to be imaged.

[0047] In use, the probe unit is held against the body of a patient adjacent to the internal part of the body which is to be imaged, with the front panel **303** in contact with the patient's skin. Electronics in the probe unit stimulate the emission of ultrasound energy from the transducer. Passive or active beamforming may be applied. This beam is reflected back to the transducer as echoes by the features to be imaged. The transducer receives these echoes which are amplified and converted to digital scanline data.

[0048] A motor moves the transducer such that the ultrasound beam or beams sweep out an area to be imaged. Electronics for control of the motor are provided in the probe unit.

[0049] In a preferred version, the linear motor is a linear ultrasonic motor.

[0050] In a further version, the ultrasonic motor is a rotary motor.

[0051] Ultrasonic motors work by stimulating vibration in a vibratory portion. This vibratory portion may be either the stator of a motor, or the slider or forcer of a linear motor or the rotor of a rotary motor, but is most usually the stator. The forcer or slider in a linear motor is the equivalent of the rotor in a rotary motor. A tip portion of the vibratory portion contacts the non-vibratory portion, by frictional coupling, causing relative movement. There is a standing-wave type which is referred to as a vibratory-coupler type, where the vibratory portion is connected to an ultrasonic driver and the tip portion generates an elliptical movement. Only one vibration source required. By comparison, the propagating-wave type combines two standing waves with a 90 degree phase difference both in time and in space. In this case a surface particle of the elastic body draws an elliptical locus due to the coupling of longitudinal and transverse waves. This type requires two vibration sources to generate one propagating wave, leading to lower efficiency, but it provides controllable drive in both directions. Ultrasonic motors using other operating principles may also be used.

[0052] The term "ultrasonic motor" is used throughout this specification. Other terms may be used for devices having the same principle of operation but varying in size, configuration and/or application. These terms include, without limitation, piezomotor, piezoelectric actuator, piezoactuator, and ultrasonic actuator. The term "ultrasonic motor" as used in this specification covers all of these and any other possible terminology which may be used to describe ultrasonically driven moving devices which may be used to perform the invention.

[0053] FIG. **4** shows a scan head of the ultrasound scanning system probe unit of FIG. **3**. There is a scan head **401** which includes a transducer slider **402**, having transducer crystals **404**. There may be as few as one transducer crystal, with the maximum number being limited only by practical considerations of cost, size and complexity. The slider is guided and constrained to move in a reciprocating fashion by guide rails **403**. In use the slider is driven in a reciprocating fashion such that the beams from the transducers cover an area to be imaged. The slider may be driven in the reciprocating motion by any convenient means.

[0054] An acoustically matched lubricant may be provided on the interior side of the front panel **409** of the scan head filling the gap between the transducer elements **404** and the panel **409**.

[0055] In a further version a strip of solid material having a low coefficient of friction and acoustic matching properties is provided on the interior side of the front panel **409** of the scan head filling the gap between the transducer elements **404** and the panel **409**.

[0056] In this version, the transducer array is an array of eight piezo-electric elements. In other versions, other numbers and other types of transducer elements may be employed. In particular versions, capacitive micro-machined ultrasonic transducers (CMUTs) or other MEMS based transducers may be used.

[0057] Referring to FIG. **5**, there is shown a diagrammatic view of a transducer slider. There is a slider body **505**, which supports or is integrally formed with transducer elements **501**.

[0058] The transducers are arrayed at a separation l **502**. The transducer slide may be moved such that the width of coverage of the linear array is the distance designated as S **504**. This is the total width able to be covered by the array over the full range of movement.

[0059] The slider is moved, continuously or in steps, the distance l. The transducer elements transmit and receive ultrasound energy whilst moving or at each step in order to receive a scanline which is a series of echo intensity values returned from features at various depths along a line running into the body to be imaged. The image displayed as an ultrasound scan image is essentially a display of a series of scanlines in the same spatial relationship as they were acquired by the transducer. Considerable post-processing may have occurred to enhance the image in a variety of ways.

[0060] In a conventional linear array transducer ultrasound probe, the signal of each transducer element is combined with a number of adjacent elements, usually 32, to produce one scanline. The lateral distance between scanlines is proportional to the linear distance between successive transducer elements in the array.

[0061] To provide a higher resolution image, without sacrificing image coverage, or to provide a wider image coverage without sacrificing resolution, requires more scanlines and hence more transducer elements. Providing additional elements is expensive. The larger transducer is itself more expensive, but the additional wiring and electronics required to access and control the additional elements (usually called channels) is also expensive.

[0062] An array with few elements, set relatively far apart gives good image width for less cost, but sacrifices the number of scanlines in the image. Moving the transducer as described allows the relatively wide gap between the transducer elements to be "filled in" with scanlines, thereby providing similar performance and image size to systems with more channels, at greatly reduced cost and complexity. The scanline density is not restricted by the physical size of the transducer elements or the spacing or number of elements.

[0063] Conventional linear array systems have transducers with a large number of elements, each cut in a rectangular shape. This generates an acoustic beamshape with a non-symmetrical pattern. It is desirable to use circular crystals, where the beamshape is circular and symmetrical. Since high end systems may have **1024** or more elements, this is not practical for conventional linear array systems.

[0064] Using a sparse array of individual transducers makes the use of circular transducers in a linear array practical.

[0065] In order to be displayed as part of a scan image, each scanline must include, or be associated with, data indicating the relative location of the transducer element which received the scanline data at the time it was received. This can be done by any means known in the art. A method based on knowledge of the rotational or linear position of the motor may be used, or the position of the slider may be directly monitored by a device such as a linear encoder.

[0066] FIG. **6** shows a version of the invention wherein the slider of the ultrasonic motor is separate from the transducer array. There is a scan head **600** which includes an ultrasonic motor **610**, consisting of excitation electrodes **604**, vibratory driver **605** and slider **608** held by a frame and guide rails. The slider includes a friction layer **609** which facilitates drive friction between the vibratory driver **605** and the slider **608**. The motor **610** is attached to a circuit board (PCB) **601**, which is positioned and supported within the scan head **600** by locating guides **602**. The PCB includes or has attached to it, ultrasonic motor control circuitry **606**. This control circuitry supplies signals to the excitation electrodes **604** in order to drive the motor **610**.

[0067] Attached to the slider is transducer array **607**. The transducers making up the array may be of any suitable type. The transducers are attached to a backing element, which is mechanically connected to the slider **608** of the motor. This arrangement simplifies the assembly and manufacture of the system, as the main PCB is mechanically connected to the motor and ultrasound transducers, and the motor can operate independently of the enclosure.

[0068] The transducers are electrically connected to circuitry on the PCB **601** which excites the transducers to produce ultrasonic output and receives and processes the electrical signals returned from the transducers.

[0069] In the illustrated version, a non-liquid friction reduction means is provided to allow the transducer array to slide easily over the acoustic window **603** which, in use, is in contact with the patient. This may be, without limitation, a solid lubricant, or the material of the acoustic window may inherently provide low friction.

[0070] In other versions, a flexible, liquid-proof, membrane may be provided between the transducer array **607** and the motor **610**, forming a closed compartment with the acoustic window. This enclosed compartment encompasses the transducer array. With the motor thus protected from liquid, the transducer array may be immersed in a liquid, which provide acoustic coupling between the transducers of the transducer array and the acoustic window. In this case the transducer array will not touch the acoustic window in use.

[0071] FIG. **7** shows three possible alternative versions for the transducer array slider for any version of the invention. There is a transducer array slider **700**, with individual transducers **701** mechanically attached to, or integrally formed with, the slider. The slider may form the slider of an ultrasonic motor, or may be attached to a separate motor slider member which forms the slider of a ultrasonic linear motor. In that case, the slider **700** as shown in FIG. **7** would be motor slider member and would not have transducers directly attached.

[0072] As shown in FIG. **7***a*, the slider may include a friction strip **703** integrally formed or mechanically attached to the body of the slider **700**. This friction strip is in contact with friction tip **702**. This friction tip is driven by ultrasonic driver **705**. In this version the ultrasonic driver is made of a piezoelectric material, but other ultrasonic vibratory materials (e.g., CMUTs) could be used. The ultrasonic driver **705** is connected to excitation electrodes **706**, **707**. When excited by an appropriate signal applied to one of the excitation electrodes the driver **705** vibrates such that vibration of the driver against the friction strip drives the slider in a linear direction. Applying an appropriate signal to the other electrode will drive the slider in the reverse direction. The slider is constrained by a frame or guides (not shown) to move in a reciprocating fashion.

[0073] In an alternative version, as shown in FIG. **7***b*, the slider **700** may be constrained and guided by guide rails **709**, **710** which bear against the edges of the slider **700**. There are piezoactuators **715**-**718** rigidly attached to the guide rails. The piezoactuators have an electrode and piezoelectric material. Application of an electrical signal at ultrasonic frequency causes the piezoelectric material to vibrate, and to induce vibration in the attached guide rail.

[0074] The slider edges and the rails **709**, **710** in pairs form the contact surfaces of a linear ultrasonic motor. Vibration is induced in the rails by electric signals applied to electrodes **715**-**718**. Electrical signals applied to a first electrode pair **715**, **716** is ninety degrees out of phase with a signal applied to a second electrode pair **717**, **718**. A travelling wave is induced into the guide rails and the slider moves by "surfing" on this wave. The phase of the waves induced in the first and second electrode pairs determines the direction of the travelling wave and hence the direction of travel of the slider.

[0075] In all versions, the rails also provide the physical support and linear guidance for the slider. There are also provided springs or similar means (not shown) to hold the contact surfaces in contact.

[0076] A further version is shown in FIG. **7***c*. The ultrasonic motor slider **730** is constructed of a vibratory material, in this version a piezoelectric material. Other ultrasonic vibratory structures could be employed. The slider is supported and guided by guide rails **720**. Attached to the slider are excitation electrodes **721**, **722**. A common drain electrode (not shown) is also provided. A voltage signal at an ultrasonic frequency is applied to the electrode **721** to induce into the slider an ultrasonic wave to drive relative motion in one direction between the slider **700** and the rails **720**. A voltage signal applied to electrode **722** is used to drive the slider in the opposite direction.

[0077] As illustrated, the slider is the slider of an ultrasonic motor, but it should be understood that the transducers may be supported by a backing element, which is mechanically attached to the slider of an ultrasonic motor. In this case, the size of the motor slider and that of the backing element have no essential relationship.

[0078] Referring to FIG. **8**, the slider may be driven by a rotary motor, which in a preferred version is an ultrasonic motor.

[0079] The range of the reciprocating movement, being the linear movement of the slider **805**, is approximately equal to d, the diameter of the drive disk **803**. The number of transducer elements **808** is N. The linear distance between successive transducer elements is l.

[0080] In order to achieve full coverage of the area to be scanned with the same density of scanlines, it is necessary that l should be less than or equal to d. Preferably l should be approximately equal to d.

[0081] Preferably:

$$d \sim l = S/N$$

[0082] The number of transducer elements used can vary depending on a number of factors including coverage area, motor speed, disk size and motor response time. In the illustrated version a 7.5 MHz scan head with eight 3 mm circular crystals **808** mounted on the slider **805** combined with a 6 mm width disk **803** provides a scan head with 48 mm (8×6 mm) coverage.

[0083] The rotational motion of the ultrasonic motor **800** is translated into reciprocating motion. There is a drive disk **803** which has an off-center pin **804** protruding from one face. The disk is attached to a shaft **802** driven by the rotary motor. The slider **805** to which the transducer element array is mounted includes a slot **807**. The off-center pin **804** of the disk is located into the slot. Rotation of the disk causes the pin to impart a reciprocating motion to the slider. The slider is restrained from motion other than reciprocation in two dimensions by rails **806** on each side.

[0084] The part of the scan head containing the transducer array, may be filled with a liquid medium to eliminate any air interfaces between the moving transducer elements **808** and the protective front panel **809** of the scan head. The transducer array compartment is separated from the motor **800** by a seal **801** around the motor rotor **802**. This prevents the liquid medium from entering and potentially damaging the motor.

[0085] In further versions the transducer may be implemented such that the array is moved in a curvilinear pattern. In such versions (not illustrated), the slider is shaped as a circle segment, while the guide rails and the front panel are shaped as arcs of a circle. Either a rotary or linear motor may be used to drive the slider. For a linear motor, the slider and guides may form a linear motor. Where a rotary motor is used, the slider has a slot which accepts the offset pin drive as for the illustrated version using a rotary motor. The slot will be trapezoidal in cross section to accommodate the fixed orientation of the drive pin. Where the radius of curvature of the slider segment is sufficiently small, a rotary motor may move the slider by directly driving a rotor arm.

[0086] In a preferred version, the motor moves the transducer array slider across the width of the area to be scanned in a reciprocating fashion. Each transducer element is fired in turn. Each firing results in a single scanline of data being collected. The delay between firing each transducer element should be at least sufficient to allow for the return of echo from that depth within the body being imaged where it is desired for an image to be obtained. The firing process repeats. Generally, each transducer element will be fired many times in the time it takes for a single reciprocation of the slider. Preferably the firing is timed such that on each successive reciprocation, the firing of each transducer element is in substantially the same places with respect to the probe unit body.

[0087] Preferably, the delay between successive firings of a transducer element is related to the width of the beam from the transducer elements such that the entire length of the area being scanned is covered by a focused beam.

[0088] In an alternative version, the system operates by firing each transducer element individually with the transducer slider at rest to acquire a set of scanlines. The motor then moves the slider a step, with the slider coming to a halt before the transducer elements are again fired acquiring a second set of scanlines. This continues until the distance l is covered. The process repeats.

[0089] The size of the step is determined to provide the required scanline density over the area to be imaged. It may be varied in use in order to optimise characteristics of the scan system such as frame rate or motor speed.

[0090] All of the acquired sets of scanlines are then combined to form one frame of a real-time ultrasound display. In order to be displayed as part of a scan image, each scanline must include, or be associated with, data indicating the relative location of the transducer element which received the scanline data at the time it was received. This can be done by any means known in the art, for example, the position of the slider may be directly monitored by a device such as a linear encoder.

[0091] The number of steps used is determined by the scanline density required and the magnitude of the transducer element separation l.

[0092] The number of transducer elements used can vary depending on a number of factors including coverage area, motor speed, scanline density desired and motor response time.

[0093] All of the scanlines acquired in one full transverse movement of the transducer constitute a single frame for display. This means that the firing rate of the transducer as a whole is determined as the product of the number of elements, the frame rate and the number of scanlines required to cover the distance between the elements at the desired density.

[0094] Other element firing regimes are possible. Where this can be done without undue interference between the scanlines, more than one element may be fired at a time. Without limitation, a means of achieving this is for the transmit pulses to be coded, for example with Barker, Golay, or Gold codes, such that the correlation between pulses from separate transducers is extremely low.

[0095] In a further version, the slider length is less than the image width S. It may be much less. The scan head and rails cover the full image width. The slider is driven in incremental steps to cover the required image width. In this version, the elements of the transducer array may be arranged at such a separation that adjacent elements give the desired scanline density. In this case, the slider may move an amount equal to its full length between each full firing of the array. In the most general case, the transducer may consist of a single element. This is not the currently preferred version since one of the limitations of ultrasonic motors is that they have low linear and rotational speeds. This poses a constraint on the speed the ultrasonic crystal can scan the region of interest and hence limits the systems frame rate. Thus using an array incorporating more than one crystal which decreases the commuting distance of the crystals and reduces the motor speed requirements is currently preferred, but further improvements in motor design may make this practical.

[0096] Pulsed Wave Doppler imaging is achieved by electronically stimulating a transducer element to produce a pulse of ultrasound and then to listen for echoes before another pulse is generated. This is done rapidly at a single location, and the variable frequency shift in the returned echoes is used to detect movement in the feature being imaged, for example blood flow. These modes are not possible with motor driven transducer systems of the prior art, since they cannot be held stationary nor rapidly and accurately repositioned.

[0097] This can be achieved by the apparatus of the current invention because ultrasonic motors have excellent response time and can be positioned extremely accurately, with errors in the nanometer range. This allows the transducer to be completely stationary at a known position when sending and receiving ultrasound pulses.

[0098] Color Doppler combines real time imaging with Doppler imaging. Real time images are displayed for the full image area at the same time as Doppler information is displayed for one or more scanlines. This is not possible for any prior art system with a moving transducer, since Doppler requires that the transmitting element be stationary in a known position and real time scanning requires that the transducer be moved.

[0099] In a version providing color Doppler functionality, the transducer is controlled to move to produce a real time moving image on a display for a user. The user is able to select an area of the displayed image for acquisition of color Doppler information. A selected element or elements of the transducer, while located above the selected area, fires the required number of pulses and receives the necessary echoes to acquire the movement information, being the color Doppler frequency shift data. The real time scan operation then continues, with the transducer being moved by the ultrasonic motor to cover the image area. When the selected element is again in the same position over the selected area, it again fires multiple pulses, refreshing the color Doppler information. The process repeats.

[0100] The color Doppler and real time information are combined into a single display, as is known in the art.

[0101] The fast response and excellent positioning accuracy of ultrasonic motors allows the transducer to come to complete stop, fire the required number of ultrasound pulses, listen to the echoes, and then move to the next line while simultaneously performing real time imaging with the other transducer elements. Limitations of the speed at which the elements can be fired will generally mean that the real time frame rate will be reduced while color Doppler is in use.

[0102] Versions using ultrasonic motors may also use a curvilinear array where the linear slider is replaced with a curvilinear slider with N transducer elements mounted on it or machined as part of the slider. The rails and the front panel would also be manufactured in a curvilinear construction. Ultrasonic motors are readily manufactured in different shapes and sizes. In versions where the slider itself is part of the motor, no special arrangement or shaping of the slider is necessary to allow it be driven by an external motor.

[0103] In alternative versions, a linear ultrasonic motor separate from the curvilinear slider may be used to move a curvilinear slider through an arc of a circle.

[0104] In another version, it is possible for the rails to be formed into a circle, and the slider driven in a continuous revolution. In this case, the transducer would be active only when it was over the body to be scanned. This is especially relevant for micro curvilinear shaped scan heads, which have a relatively tight radius of curvature so as to enable imaging between ribs. Two or more transducers may be provided, each having a different operating frequency, allowing simultaneous or separate scanning at different frequencies. Doppler imaging would be possible as described for other versions.

[0105] One of the drawbacks of ultrasonic motors is the limited lifetime due to the frictional drive. A spring like mechanism is required to maintain the force between the stator and the slider/rotor. Contact areas are required between the stator and the slider to provide the frictional drive, and these contact surfaces wear. This wear increases the separation between the contact surfaces, reducing the effectiveness of the drive. This problem can be mitigated by using a piezoelectric actuator as the spring like mechanism to provide the force between the stator and slider/rotor. The force imposed by the actuator is proportional to a DC voltage across the actuator. This DC voltage in effect pushes the piezoelectric driver closer into the frictional coating and hence the coupling force between the stator and the slider is maintained throughout the life time of the motor. The magnitude of the DC voltage can be controlled so that it is increased with the motor's operating life to compensate for the layer wear.

[0106] Ultrasonic motor efficiency is insensitive to size and hence they are superior in the mini-motor area. This allows for the construction of devices of small size and low weight.

[0107] Ultrasonic motors do not produce the electromagnetic interference which is inherent in the operation of electromagnetic motors. This is an advantage for ultrasound systems where the electrical signals being received are inherently of low power and susceptible to interference. This has a further advantage for hand held ultrasound systems in reducing the need for shielding between the electronic components and the motor, which reduces size, weight and cost.

[0108] In order to produce ultrasound energy for scanning, the ultrasound transducer elements are stimulated by a high voltage power supply. This high power supply would generally supply power at voltage magnitudes on the order of tens or hundreds of volts. The ultrasonic elements which form the ultrasonic motors in those versions which employ ultrasonic motors are also driven by high voltage power supplies which may have similar output characteristics. In further versions, the ultrasound transducer elements and the ultrasonic motor are driven from a common power supply or power supplies. This results in lower costs.

[0109] In FIG. **9**, there is shown an architecture of a version of the present invention. The block diagram shows a probe unit, including a scan head **901** and a probe unit body **903**. There may also be a host unit (not illustrated) providing a display and at least part of a user interface, connected to the system using a USB interface **920**.

[0110] Small size and weight are desirable for the probe unit to facilitate hand held use. In an exemplary version, the size of the probe unit is about 15 cm×8 cm×3 cm. In a further version, the weight of the probe unit is 500 g or less. In a preferred version the size of the probe unit is about 11 cm×6 cm×2 cm and the weight is about 200 g.

[0111] The scan head **901** includes transducers **906**, arranged as a transducer array on a slider element **905**. The slider element is driven by ultrasonic motor **908**. The position of the slider **905** is monitored by position encoder **907**.

[0112] The transducers **906** are connected to multiplexer **909**. Electrical signals to excite the transducers to produce ultrasound output, and the electrical signals from the transducers in response to received echoes, are passed through the multiplexer **909**.

[0113] User control of the ultrasound scanning system is via a user interface which may be provided wholly on the host unit, wholly on the probe unit, or split or duplicated between the probe unit and the host unit. In the illustrated version there is a User Control Panel **902** incorporated in the probe unit, the Panel including a freeze button to start and stop scanning, a set of buttons providing increment, decrement and select functionality, and a "back" button. These buttons are used for basic control of the system, including without limitation, some or all of start and stop scan, depth adjustments, gain adjustments, operating mode selections, and preset selections as well as other basic settings. The user control panel **902** sends data identifying the state of the buttons to a micro-Controller **930**, which in this version is part of a combined microcontroller/DSP device such as the OMAP3525 Applications Processor from Texas Instruments. The microcontroller monitors the state of the control panel and provides appropriate commands to control the appropriate electronic circuitry to allow the user to control the ultrasound system. Where this requires a graphical user interface, this is displayed on the host unit.

[0114] The microcontroller **930** contains a set of parameters for controlling the operation of the device during scanning. At initial power up, a default set of parameters are created, which can then be modified by the user before or during scanning. The parameters include without limitation, the operating frequency, the active scanning mode, the gain curve, the scanning depth, the Doppler gate depth and angle if required, color Doppler ranges if required, power Doppler ranges if required, and M-mode pulse repetition rate. The scanning modes available may include, without limitation any or all of B-mode, M-mode, and modes available using

Pulse Wave Doppler, including color Doppler, power Doppler and spectral Doppler, and Duplex Doppler. 3D volume imaging can also be performed.

[0115] The microcontroller writes the relevant parameters to the Digital Signal Processor (DSP) **931** and Field Programmable Gate Array (FPGA) **932** when scanning is activated or the parameters change.

[0116] When a user commences a scan, either by pressing a button on the control panel or by activating a control on the host, the microcontroller sends a command to the DSP and Field Programmable Gate Array (FPGA) to activate scanning, along with any updated configuration parameters. The DSP is configured to receive and process ultrasound data according to the parameters, which may include parameters concerning Doppler processing.

[0117] The microcontroller and the FPGA together provide the functionality to control the scan head ultrasonic motor. The ultrasonic motor position encoder **908** produces a value proportional to the position of the ultrasonic motor at any point in time. This position is saved with a timestamp in a register in the FPGA, and the microcontroller reads this information to calculate a velocity. The velocity is compared with the desired velocity. The motor control unit **910** is instructed to alter the voltage and frequency of the drive signal applied to the ultrasonic motor **908** in order to achieve the desired velocity.

[0118] FIG. **14** illustrates the FPGA functionality. The FPGA receives and decodes the output of the ultrasonic motor position encoder **907**, and provides the information to the microcontroller in order for it to recalculate the ultrasonic motor drive signals. The FPGA includes a timing state machine **145** which uses the decoded position information to determine the appropriate time to generate the next ultrasound pulse sequence to be output from the transducers, which is achieved by driving the transmit pulse controller **144**.

[0119] Transmit pulse controller **144** generates control signals corresponding to the type of scan line required to be generated. For a B-mode scan line, a single pulse is generated at the imaging frequency at the voltages provided by the High Voltage power supply (HV Supply) **934**. These voltages are typically up to +−100V. For Doppler a sequence of several pulses, typically eight pulses, at the Doppler imaging frequency is generated. These Doppler pulses are typically of longer duration than B-mode pulses. The multiplexer is preconfigured before the Tx Pulser **933** fires to steer the transmit pulse to the appropriate circular transducer crystal. The transducer crystal **906** generates an ultrasonic waveform in response to the electrical pulse, which is transmitted into a body to be imaged.

[0120] The ultrasonic waveform is reflected by changes in acoustic impedance, producing echoes which are received back at the transducer crystal **906** at lower pressure. The crystal converts this lower pressure waveform into an electrical signal, which is directed through the multiplexer to the input protection circuitry **935**. The input protection circuitry protects the sensitive low noise amplified (LNA) **936** from the high voltage transmit pulse while letting through a low voltage receive signal. Several input protection circuits are known in the prior art.

[0121] The low noise amplifier (LNA) provides amplification of the small receive signal, while adding little noise to the output signal. The LNA is typically single ended, and generates a differential output voltage for feed into a time gain amplifier (TGA) **937**. The TGA provides further amplification with the amplification provided being dependent on time. Ultrasound signals attenuate as they propagate through tissue, and the TGA compensates for this attenuation by increasing the gain dependent on the time from the beginning of the received pulse, which is proportional to the depth of the echo reflection.

[0122] The output of the time gain amplifier is filtered to remove as much noise as possible and to prevent aliasing. Typically a bandpass filter **938** is used. The output of the filter is input to the analog to digital converter **939**. A sampling frequency of at least 4× the imaging frequency is preferred. The analog to digital output is input to a first in first out memory (FIFO) **147** in the FPGA **932**. The FPGA adds some header information to each complete scan line, including the type of scan line (for example, B-mode or Doppler), the motor positional encoder input if required, and a time count. This information may be used at a later stage in processing dependent on the configuration parameters.

[0123] The DSP reads the scan lines out of the FPGA FIFO, and performs appropriate processing on the data depending on the configuration parameters.

[0124] FIG. **10** is a configuration of the system which does not have real-time ultrasound capability, but uses a lower cost single channel system where the ultrasound beam is stationary with respect to the system. A single transducer **1001** is provided, which is in a fixed relationship to the probe unit body. There is also provided a gyroscope **1002**. Images created by moving the probe unit in an arc with the point of contact of the scan head **1003** with the patient being substantially constant while the transducer is pulsed. This will generate a sequence of scan lines which together make up a sector image. The gyroscope provides information as to the relative position of each scan line, enabling the scan lines to be assembled into an image.

[0125] FIG. **11** illustrates a further version of the invention, where the scan head **1101** contains a motor **908** and a gyroscope **1103**. The gyroscope is oriented so it provides angular measurements perpendicular to the image plane of the B-mode image which is produced from the transducer array **1102**. By providing the gyroscope, the system is able to construct 3D images from a sequence of 2D image scans, and determine volumes. In use, a series of B-mode images are made as for the system of FIG. **9**. The probe unit is moved in an arc perpendicular to the image plane of the B-mode images. The operation is otherwise similar to the system as described in FIG. **9**.

[0126] Referring to FIG. **14**, The FPGA timing state machine **145** interfaces to the gyroscope in versions where a gyroscope is provided. The gyroscope angular measurement is combined with the ultrasound scan line information in a first in first out (FIFO) memory **147**, and read by the digital signal processor (DSP). Where a single transducer is used, the gyroscope information is used to assemble the scan lines to form a sector image. Where a transducer array is used, the gyroscope information is used to assemble B-mode sector images into a representation of a volume which may also be used for any applications which require 3D volume calculations.

[0127] FIG. **12** illustrates an alternative version of the invention, whereby the interface to the host display and control system is via a wireless interface. There is provided a wireless interface module **1202** controlled by the microprocessor **930**. An antenna **1201** is provided for signal transmission. This interface provides communication to and from the host unit. No USB interface is required for communication with the host unit, although one may be provided for access to third party hardware. In a presently preferred version the wireless protocol used is WiFi Direct.

[0128] FIG. **13** illustrates an alternative version of the invention, wherein there is no host unit. There is provided a display **1301** which is integral with the probe unit. There is also provided an enhanced user control module **1302**. This includes the functionality of the control panel of previously described versions, but further includes functionality allowing for full control of the system in the absence of a host unit. The control module may include a graphical user interface displayed on the display **1301**. The display may be a touch-screen, able to provide input to the user interface.

[0129] The operation of the DSP in different versions will vary. Where a host control and display system is connected, some processing and control functions and the display function may be performed by the host unit. Where no host is used, all functions are performed by the probe unit, increasing the load on the DSP. Limitations on the division of functionality between a host and the probe unit come from the processing power of the host and the bandwidth available for transmission between the host and the probe unit. In general, the implementation and subdivision of algorithms is designed to minimise the host processing requirements and the bandwidth required for transmission.

[0130] FIG. **15** illustrates the algorithms for processing combined B-mode/Doppler, with a division of the tasks between the ultrasound probe unit and the host display system.

[0131] The first step in the B-Mode processing chain is to filter the digitised incoming rf scan line data using an FIR bandpass filter. The filter is adjusted depending on the transducer connected to the system and the imaging frequency. For example, for a 3 MHz imaging frequency a bandpass filter of 1 to 5 MHz could be used. For an 8 MHz imaging frequency a bandpass filter of 4.5 to 11.5 MHz could be used. Following filtering, the envelope of the rf scan line data is generated. The preferred method is to use a Hilbert transform to generate the in-phase (I) and quadrature (Q) components of the rf scan line. The final envelope is generated by summing the squares of the I and Q components, and taking the square root of the result.

$$\text{Envelope}=\sqrt{I^2+Q^2}$$

[0132] There are a number of algorithms for generating Hilbert Transforms. The preferred version is using an FIR approximation.

[0133] Following envelope generation, the scan line can be downsampled or decimated. Downsampling by a factor of 2-4 is possible, depending on the scan conversion algorithm used. In the preferred version, the scan line is downsampled by a factor of 4 with scan conversion using bilinear interpolation. An alternative is to downsample by a factor of 2 and use a less compute intensive interpolation algorithm, such as one which computes pixel intensity from the average of sample points inside the pixel area, and interpolates for other pixels between adjacent pixels.

[0134] Following downsampling, the scan line is compressed from the analog to digital word size into an 8 bit word size to map the signal into the desired grey scale levels for display.

[0135] The downsampled scan lines are then converted to a rectangular image display through scan conversion. The scan conversion is performed in 2 stages. The first stage is converting the image into a compressed rectangular array with high resolution, preferably with pixel resolution of less than half the axial resolution of the ultrasound pulse. A common scan conversion algorithm is a 2×2 bilinear interpolation, mapping the scan line points from a polar co-ordinate system to a rectangular co-ordinate system. Referring to FIG. **16***a* there is shown an idealised scan from a phased array transducer. The scan area **1602** can be seen as a sector of a circle, with origin **1601**. In practice, phased array transducer is not a point source, but it is small compared to the depth of scan. The location of each scanline **1603** can be characterised in polar co-ordinates by a length r and an angle θ. Referring to FIG. **16***b*, there is shown a sector scan for a curvilinear array with a radius of curvature R and a width w. The scan is a truncated sector of a circle. Each scanline **1605** can be characterised by polar co-ordinates of a length R+r and an angle θ.

[0136] The natural co-ordinates for a linear array scan as shown in FIG. **16***c* shows an idealised scan for a linear array. The characterising co-ordinates are linear, but in general will not correspond to the linear co-ordinate system desired for display.

[0137] For sector shaped images, the compression algorithm reduces the image size by ignoring image area which is not containing actual image data. Several methods are possible to perform this, with one being a simple format where each pixel row contains a header with the starting pixel and number of pixels with valid data. This technique yields a compression ratio of close to 2. Another lossless technique which would provide reasonable results is run-length encoding. LZW encoding, or Huffman based encoding such as png could be used.

[0138] The high resolution compressed rectangular array is handled differently depending on the system configuration. The array is stored in a local memory, with typically up to 100 compressed frames being stored locally. At the same time the current frame is transmitted from the ultrasound probe to a host display system. The host display system completes the processing by decompressing the image into a high resolution buffer, interpolating from the high resolution buffer to an interim display image buffer, applying any grey scale adjustment, combining with any Doppler image information if required, and finally writing to the display buffer.

[0139] FIG. **15** also illustrates the steps required for processing and displaying Doppler information overlayed on the B-mode image. When generating Doppler information, the system generates a sequence of Doppler pulses with a consistent phase and processes the received set of scan lines. The raw input rf scanlines are quadrature encoded, with the inphase (I) and quadarture (Q) components extracted by multiplying the echo signal by the cosine and sine of the transducer excitation frequency. The I and Q outputs from the quadrature encoder are low pass filtered and decimated or downsampled. A downsampling ratio of four produces satisfactory results, but other factors may be employed. The output of the downsampler is saved into a buffer until a complete set of scan lines is received. Typically a set will be eight scan lines, although the size of the set can be adjusted. The data set is filtered using a wall filter. The function of the wall filter is to reduce contribution from large, slow moving features such as an abdominal wall.

[0140] The wall filter in the illustrated version is an FIR type high pass filter. An alternative is to use a state-space formulation IIR filter, which reduces the transient response length of the IIR filter. The state-space initialisation provides satisfactory attenuation using a step initialisation scheme.

[0141] In the preferred version the filtered set of scan lines is processed using autocorrelation techniques to generate velocity, power, and turbulence information. The Doppler power of the set of scan lines is calculated as follows:

$$P_d = \sum_{k=0}^{n-2} S_{d,k} \cdot S_{d,k}^*$$

[0142] The correlation between adjacent scan line points is calculated as follows:

$$C_d = \sum_{k=0}^{n-2} S_{d,k+1} \cdot S_{d,k}^*$$

[0143] The velocity estimation is calculated as follows:

$$v_d = \tan^{-1}\left(\frac{Im(c_d)}{Re(c_d)}\right)$$

[0144] Turbulence estimation is calculated as follows:

$$t_d = 1 - \left(\frac{|c_d|}{P_d}\right)$$

where

[0145] s is the complex representation of a scan line (s=I+jQ)

[0146] d is the sample at a depth in a scan line.

[0147] k is the scan line number in a set of scan lines.

[0148] When the system is configured for power Doppler, only the power estimation is required. The correlation between adjacent scan lines, velocity, and turbulence are not required. When the system is configured for color Doppler, the system calculates velocity, and optionally power and turbulence. The output of the flow and turbulence estimation is scan converted to a rectangular array, of size 200×200×8 for each flow estimator. The rectangular arrays are compressed using a simple lossless compression algorithm. FIG. **17** provides an illustration of a typical Doppler window **1702**, where the Doppler processing area is limited with respect to the full B-mode image **1701** size. This improves the compression of the 200×200×8 arrays, as a large proportion of the array is empty. The compressed array are transmitted to the host, with a further interpolation step to the required Doppler image window, and color map conversion. Positive velocities are encoded in red shades, while negative velocities are encoded in blue shades. Turbulence is encoded in green. When power Doppler is selected, only red shades are used to represent the total power of the Doppler signals.

[0149] An alternative version of the invention is to provide a system which plots power Doppler with different color schemes used depending on whether the direction of flow is positive or negative. The power Doppler is calculated as above, scan converted, and transmitted to the host. In parallel, an efficient method is used to determine the direction of the flow. The full correlation between adjacent scan line points can be used, with the sign of the real and imaginary outputs used for each point to determine a direction. Alternatively, for imaging where sensitivity is not an issue, the correlation to decode direction can be shortened, and use a smaller set of scan lines. Power is optimised by providing a system which has feedback, where a small set of scan lines is used, and if the direction result is unstable (changing rapidly) the number of scan lines is increased to maximum. Then when the result is stable, the system runs a test correlation in parallel on a smaller set of scan lines and if that result is stable moves to using the smaller set. The system therefore optimises the power transmitted into the body, and minimises power consumption.

[0150] The system supports Cine playback or video recording. For Cine playback, the ultrasound probe stored compressed 500×500×8 B-mode frames into local DSP memory. 100 frames provides around five seconds of automatic Cine recording. When the user instructs the host user interface to scroll back through recorded frames, the DSP transmits the compressed frames up to the host and scan conversion is completed as per normal operation. For video recording, when the user instructs the host to record a segment to video, the DSP activates operations to complete any scan conversion and Doppler combining, and runs a video encoder which records the real-time images to a video format saving directly to memory, preferably at 640×480 pixel resolution. The video file can then be played back by a video decoder streaming data to a frame buffer which is transmitted to the host for display.

[0151] The system can be configured to operate in M-mode or duplex mode where a B-mode image and M-mode image are shown on the same screen.

[0152] In M-mode or Duplex mode, the DSP reads the M-mode scan lines and interpolates each scan line to a 500×1×8 buffer. The M-mode buffer is transmitted to the host which performs grey scale adjustment and renders the scan line to the display.

[0153] For duplex mode, two sorts of M-mode are possible. Full duplex is where an M-mode scan line is placed on a realtime B-mode image, and the M-mode pulse repetition rate is the same rate as the B-mode image update rate, typically 20 frames per second.

[0154] For quasi duplex mode, a high M-mode frame rate is required, such as for looking at rapidly moving heart valves. In this mode, an M-mode line is placed on a B-mode image, and when the select button is pressed the B-mode image is frozen and the M-mode graph is rendered to the screen.

[0155] A quasi duplex gated Doppler mode is also provided. A Doppler line is placed by the user on a B-mode image, and a gate area moved along the line to select the area for Doppler analysis. The gate angle can also be adjusted. When the select button is activated, the B-mode image is frozen, and a time/velocity graph plotted. The Doppler signal is processed in a similar way to color Doppler, except the scanlines are repeatedly pulsed only along the selected line (rather than moving across the image). In addition, the user selects a particular depth of interest, and the received echoes are 'range gated' such that only Doppler information from the depth of interest is analysed. This provides a large number of scanlines from the region of interest; frequency analysis is carried out on large groups of these scanlines (say 256) at a time, with the preferred method being applying the Fast Fourier Transform (FFT) on the complex representation of a group of scanlines. Each FFT performed provides a frequency spectrum of the Doppler signal shift, and these spectra can be displayed together to generate a time-frequency plot of the flow characteristics at the depth of interest which is often called 'spectral Doppler'. Spectral Doppler enables visualisation of how the velocity and power of blood flow changes with time for the selected region of interest.

[0156] Although the invention has been herein shown and described in what is conceived to be the most practical and preferred version, it is recognised that departures can be made within the scope of the invention, which is not to be limited to the details described herein but is to be accorded the full scope of the appended claims so as to embrace any and all equivalent devices and apparatus.

What is claimed is:

1. An ultrasound transducer probe unit including a body portion and at least one transducer for transmitting and receiving ultrasonic signals, wherein the transducer is moved with respect to the body portion in a repetitive motion by an ultrasonic motor.

2. The probe unit of claim **1** wherein the probe unit is configured to produce scanline data suitable for processing to enable display of at least one of gated Doppler, color Doppler, power Doppler, and spectral Doppler.

3. The probe unit of claim **1** wherein the transducers are situated in an array.

4. An ultrasound transducer probe unit including an ultrasound transducer unit having an array of transducers wherein the transducer unit is configured to move in a reciprocating motion by a selected linear distance along a linear path, the linear separation between the transducers of the transducer unit along the linear path being of approximately the same magnitude as the linear distance, the probe unit being operated to acquire scanlines during each reciprocation.

5. The probe unit of claim **4** wherein the reciprocating motion consists of discrete steps, with a scanline being acquired only when the transducer is stationary.

6. The probe unit of claim **4** wherein the transducer movement is driven by an ultrasonic rotary motor.

7. The probe unit of claim **4** wherein the transducer movement is driven by an ultrasonic linear motor.

8. The probe unit of claim **4** wherein the linear path is a curvilinear path.

9. An ultrasound transducer probe unit including a body portion and at least one transducer for transmitting and receiving ultrasonic signals, the transducer being configured to mechanically move with respect to the body portion in a repetitive motion in order to insonify an area, wherein the movement of the transducer is able to be controlled to return to a selected position relative to the body portion with an error of less than 1 millimeter.

10. The probe unit of claim **9** wherein the movement of the transducer is controlled to return to a selected position relative to the body portion with an error of less than 500 micrometers.

11. The probe unit of claim **9** wherein the movement of the transducer is controlled to return to a selected position relative to the body portion with an error of less than 500 nanometers.

12. The probe unit of claim **9** wherein the movement of the transducer is controlled to return to a selected position relative to the body portion with an error of less than 100 nanometers.

13. The probe unit of claim **1** wherein the weight of the probe unit is less than 500 grams.

14. The probe unit of claim **1** wherein the weight of the probe unit is less than 200 grams.

15. The probe unit of claim **1** wherein the probe unit is sized to be conveniently hand held.

16. The probe unit of claim **1** wherein the probe unit has a maximum linear dimension of 15 centimeters.

17. The probe unit of claim **1** wherein the probe unit has a maximum linear dimension of 12 centimeters.

18. A method of ultrasound scanning wherein there is provided one or more ultrasound transducers, the method including the steps of:

a. moving the transducers in a repetitive motion with respect to a body to be imaged by an ultrasonic motor,
b. producing an ultrasound image for display, the image including scanlines acquired by the transducers at consecutive points along the path of movement, with each transducer contributing scanlines to the image.

19. The method of claim **18** further including the steps of:

a. selecting an area of the image as a Doppler window;
b. moving the transducer and acquiring image scanlines,
c. stopping the transducer at a stop position such that a scanline acquired by the transducer will fall into the Doppler window,
d. acquiring scanlines for Doppler processing at the stop position,
e. again moving the transducer and acquiring image scanlines,
f. returning the transducer to the stop position and acquiring further scanlines for Doppler processing, the return to the stop position being done with an accuracy sufficient to allow for continuing Doppler imaging,
g. processing the scanlines to provide a display to a user of an ultrasound image with Doppler information.

20. The method of claim **18** wherein the ultrasound scanning functionality includes B-mode and at least one of M-mode, gated Doppler, power Doppler, color Doppler, spectral Doppler and 3D volume imaging.

21. The method of claim **18** wherein the movement of the transducer array is in discrete steps with image scanlines being acquired only when the transducer is at least substantially stationary.

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摘要(译)

一种具有换能器探头单元的超声系统，该换能器探头单元包括至少一个用于发送和接收超声波信号的换能器，其中换能器通过超声波马达以重复运动相对于探头单元移动。