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(71) Applicant: **BFLY OPERATIONS, INC.** [US/US]; 1600 District Ave, Burlington, MA 01803 (US).

(72) Inventors: **KIM, Seungsoo**; 1600 District Ave, Burlington, MA 01803 (US). **THIELE, Karl**; 1600 District Ave, Burlington, MA 01803 (US).

(74) Agent: **WATANABE, Yuichi** et al.; Osha Bergman Watanabe & Burton LLP, 1100 Louisiana Street, Suite 4900, Houston, TX 77002 (US).

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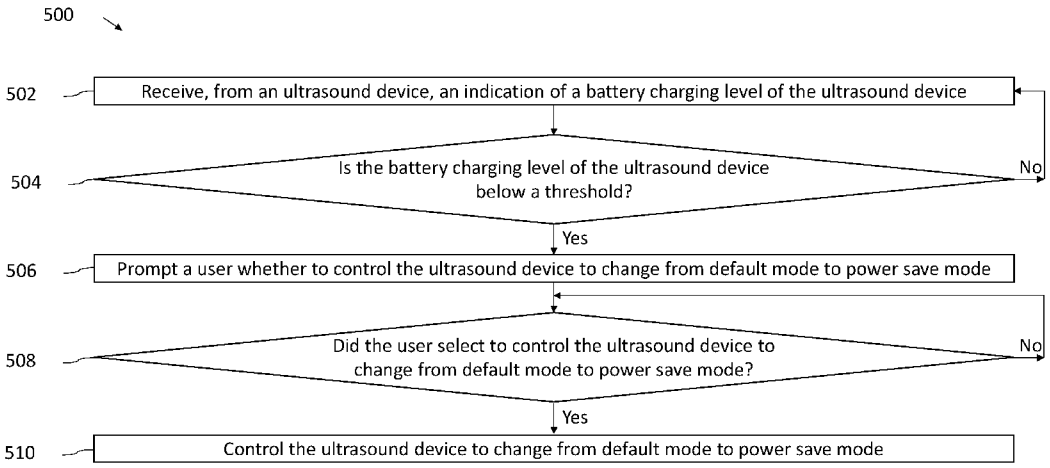

FIG. 5

(57) Abstract: An ultrasound device may change from a default mode to a power save mode by modifying parameter values of ultrasound circuitry in the ultrasound device. Modifying the parameter values may include controlling bias generators to reduce bias currents supplied to amplifiers in receive circuitry, controlling multiplexing circuitry to increase the number of the ultrasound transducers coupled to transimpedance amplifiers (TIAs) and controlling other TIAs to turn off, controlling amplifiers and an analog-to-digital converter (ADC) to turn off, and/or controlling a waveform generator to decrease a frame rate of ultrasound imaging performed by the ultrasound device. There may be different power save modes for different anatomical region types.

[Continued on next page]

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ULTRASOUND DEVICES CONFIGURED TO CHANGE FROM DEFAULT MODE TO POWER SAVE MODE AND METHODS ASSOCIATED WITH THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to United States Provisional Patent Application Serial No. 63/296,395, titled "ULTRASOUND DEVICES CONFIGURED TO CHANGE FROM DEFAULT MODE TO POWER SAVE MODE AND METHODS ASSOCIATED WITH THE SAME," which was filed on January 4, 2022, and is incorporated herein by reference.

FIELD

[0002] Generally, the aspects of the technology described herein relate to ultrasound devices. Certain aspects relate to power save mode for ultrasound devices.

BACKGROUND

[0003] Ultrasound devices may be used to perform diagnostic medical imaging and/or treatment, using sound waves with frequencies that are higher than those audible to humans. Ultrasound imaging may be used to see internal soft tissue body structures. When pulses of ultrasound are transmitted into tissue, sound waves of different amplitudes may be reflected back towards the probe at different tissue interfaces. These reflected sound waves may then be recorded and displayed as an image to the operator. The strength (amplitude) of the sound signal and the time it takes for the wave to travel through the body may provide information used to produce the ultrasound image. Many different types of images can be formed using ultrasound devices. For example, images can be generated that show two-dimensional cross-sections of tissue, blood flow, motion of tissue over time, the location of blood, the presence of specific molecules, the stiffness of tissue, or the anatomy of a three-dimensional region.

SUMMARY

[0004] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

[0005] In general, in one aspect, some embodiments relate to an ultrasound device. The ultrasound device includes ultrasound transducers, an ultrasound transducer array that includes the ultrasound transducers and having an azimuthal dimension and an elevational dimension, and ultrasound circuitry. The ultrasound circuitry includes receive circuitry that includes one or more amplifiers and an analog-to-digital converter (ADC), wherein the one or more amplifiers include transimpedance amplifiers (TIAs). The receive circuitry further includes multiplexing circuitry configured to couple a number of the ultrasound transducers to each of certain of the TIAs. The ultrasound circuitry further includes one of more bias generators configured to supply bias currents to the one or more amplifiers of the receive circuitry. The ultrasound circuitry further includes transmit circuitry that includes a pulser configured to drive the ultrasound transducers to emit ultrasound signals, and a waveform generator configured to control the pulser to emit the ultrasound signals such that the emitted ultrasound signals have particular waveforms. The ultrasound circuitry further includes control circuitry configured to receive a control signal to change from a default mode to a power save mode. The control circuitry is further configured to, based on receiving the control signal, cause the ultrasound device to change from the default mode to the power save mode. Causing the ultrasound device to change from the default mode to the power save mode includes modifying, by the control circuitry, one or more parameter values of the ultrasound circuitry from default mode parameter values to power save mode parameter values. Modifying the one or more parameter values of the ultrasound circuitry may include controlling, by the control circuitry, the one or more bias generators to reduce one or more of the bias currents supplied to one or more of the amplifiers in the receive circuitry. Modifying the one or more parameter values of the ultrasound circuitry may further include controlling, by the control circuitry the multiplexing circuitry to increase the number of the ultrasound transducers coupled to each of certain of the TIAs. Modifying the one or more parameter values of the ultrasound circuitry may further include controlling, by the control circuitry certain other of the TIAs to turn off. Modifying the one or more parameter values of the

ultrasound circuitry may further include controlling, by the control circuitry, the one or more amplifiers and the ADC of the receive circuitry to turn off. Modifying the one or more parameter values of the ultrasound circuitry may further include controlling, by the control circuitry, the waveform generator to decrease a frame rate of ultrasound imaging performed by the ultrasound device.

[0006] In general, in one aspect, some embodiments relate to an ultrasound device. The ultrasound device includes ultrasound transducers and an ultrasound transducer array that includes the ultrasound transducers and having an azimuthal dimension and an elevational dimension. The ultrasound device further includes ultrasound circuitry that includes receive circuitry, transmit circuitry, and control circuitry. The control circuitry is configured to determine a first anatomical region type of a subject that is being analyzed using the ultrasound transducer array. The control circuitry is further configured to receive a first control signal to change from a default mode to a first power save mode among a plurality of power save modes, wherein the first power save mode is associated with the first anatomical region. The control circuitry is further configured to, based on receiving the first control signal, cause the ultrasound device to change from the default mode to the first power save mode associated with the first anatomical region. A respective power save mode among the plurality of power save modes is different for different anatomical region types.

[0007] Other aspects and advantages of the claimed subject matter will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Various aspects and embodiments will be described with reference to the following exemplary and non-limiting figures. It should be appreciated that the figures are not necessarily drawn to scale. Items appearing in multiple figures are indicated by the same or a similar reference number in all the figures in which they appear.

[0009] FIGs. 1 and 2 illustrate various systems in accordance with one or more embodiments.

[0010] FIGs. 3, 4A, and 4B illustrate various examples in accordance with one or more embodiments.

[0011] FIGs. 5, 6, 7, 8 and 9 illustrate various flowcharts in accordance with one or more embodiments.

[0012] FIGs. 10 and 11 illustrate various systems in accordance with one or more embodiments.

DETAILED DESCRIPTION

[0013] Recently, medical ultrasound imaging devices have been developed that include ultrasound transducers integrated onto a semiconductor die along with ultrasound circuitry. Aspects of such ultrasound-on-a chip devices are described in U.S. Patent Application No. 15/415,434 titled "UNIVERSAL ULTRASOUND DEVICE AND RELATED APPARATUS AND METHODS," filed on January 25, 2017 (and assigned to the assignee of the instant application), published as U.S. Pat. Pub. No. 2017/0360397 A1, and issued as U.S. Pat. No. 10,856,840, which is incorporated by reference herein in its entirety. Such ultrasound devices may include thousands of ultrasound transducers and more than one thousand instances of receive circuitry configured to process signals from the ultrasound transducers. Each instance of receive circuitry may include a transimpedance amplifier (TIA), averaging circuit, auto-zero block, time gain compensation circuit, ADC driver, and ADC, or more than one of each. The ultrasound circuitry on such an ultrasound device may consume significant power, causing heating of the ultrasound device and depletion of the battery.

[0014] Some embodiments allow an ultrasound device to change from a default mode to a power save mode. To change from default mode to power save mode, control circuitry in the ultrasound device may modify one or more parameter values of ultrasound circuitry in the ultrasound device from default mode parameter values to power save mode parameter values. As one example, the control circuitry may control bias generators to reduce bias currents supplied to amplifiers in the receive circuitry. As another example, the control circuitry may control multiplexing circuitry to increase the number of ultrasound transducers coupled to certain TIAs, and turn off other TIAs. As another example, the control circuitry may cause entire instances of receive circuitry to shut off, such that the elevational aperture and/or azimuthal aperture of the ultrasound device is reduced in size. As another example, the control circuitry may control waveform generators to reduce the frame rate of ultrasound imaging performed by the ultrasound device. For example, some embodiments have optimized the various parameter values modified in power save mode as a function of the particular anatomical region(s) or structure(s) being imaged. In other words, power save mode may be different for different presets, where a preset is a set of imaging parameter values for configuring the ultrasound device that are optimized for imaging a particular anatomical region(s) or structure(s).

[0015] Furthermore, some embodiments controlling when the ultrasound device changes

from default mode to power save mode. (As referred to herein, a default mode may be any mode not optimized for saving power to the same extent as the power save mode.) As one example, a processing device (e.g., a smartphone, tablet, or laptop) in operative communication with the ultrasound device may receive an indication of the battery charging level of the ultrasound device and determine that the battery charging level of the ultrasound device is below a threshold. As another example, the processing device may receive an indication of the temperature of the ultrasound device and determine that the temperature of the ultrasound device is above a threshold. In either example, the processing device may prompt the user whether to control the ultrasound device to change from default mode to power save mode, and based on determining that the user selected to control the ultrasound device to change from default mode to power save mode, control the ultrasound device to change from default mode to power save mode in the manner described above.

[0016] Various aspects of the present disclosure may be used alone, in combination, or in a variety of arrangements not explicit in the foregoing embodiments and are therefore not limited in their application to the details and arrangement of components set forth in the foregoing description or illustrated in the drawings. For example, aspects described in one embodiment may be combined in any manner with aspects described in other embodiments.

[0017] FIG. 1 illustrates a schematic block diagram of an example ultrasound system 100 upon which various aspects of the technology described herein may be practiced. The ultrasound system 100 includes an ultrasound device 102, a processing device 104, a network 106, and one or more servers 108. The ultrasound device 102 may be any of the ultrasound devices described herein. The processing device 104 may be any of the processing devices described herein.

[0018] The ultrasound device 102 includes ultrasound transducers 110, ultrasound circuitry 112, a battery 117, battery monitoring circuitry 119, temperature sensing circuitry 121, an inertial measurement unit 123, and optionally a processor 114, memory 116, and an input device (not shown). The processing device 104 includes a display screen 118, a processor 120, memory 122, an input device 124, a camera 126, and a speaker 128. The ultrasound device 102 and the processing device 104 are in wired communication (e.g., through a lightning connector or a mini-USB connector) and/or wireless communication (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols). The processing device 104 and the one or more servers 108 are in wireless communication over the network 106.

[0019] The ultrasound device 102 may be configured, in general, to generate ultrasound data

that may be employed to generate an ultrasound image. The ultrasound transducers 110 of the ultrasound device 102 may include, for example, one or more capacitive micromachined ultrasound transducers (CMUTs), one or more CMOS (complementary metal-oxide-semiconductor) ultrasound transducers (CUTs), one or more piezoelectric micromachined ultrasound transducers (PMUTs), and/or one or more other suitable ultrasound transducer cells. The ultrasound transducers 110 may be, for example, any of the ultrasound transducers 1002 described herein. The ultrasound circuitry 112 may be configured to generate ultrasound data, and may include any of the ultrasound circuitry described herein (e.g., any or all of the ultrasound circuitry 200 and/or the CIC filter) and may include more circuitry than illustrated herein. The ultrasound circuitry 112 may be integrated circuitry. In some embodiments, some or all of the ultrasound circuitry 112 may be monolithically integrated onto the same semiconductor die as the ultrasound transducers 110. The ultrasound device 102 may transmit ultrasound data and/or ultrasound images to the processing device 104 over a wired (e.g., through a lightning connector or a mini-USB connector) and/or wireless (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols) communication link.

[0020] The processor 114 may include specially-programmed and/or special-purpose hardware such as an application-specific integrated circuit (ASIC). For example, the processor 114 may include one or more graphics processing units (GPUs) and/or one or more tensor processing units (TPUs). TPUs may be ASICs specifically designed for machine learning (e.g., deep learning). The TPUs may be employed, for example, to accelerate the inference phase of a neural network. The ultrasound device 102 may be configured to perform certain of the processes (e.g., the processes 7-9) described herein using the processor 114 (e.g., control circuitry in the processor 114) and one or more articles of manufacture that include non-transitory computer-readable storage media such as the memory 116. In particular, to perform certain of the processes described herein, the processor 114 may execute one or more processor-executable instructions stored in one or more non-transitory computer-readable storage media (e.g., the memory 116), which may serve as non-transitory computer-readable storage media storing processor-executable instructions for execution by the processor 114. The processor 114 may control writing data to and reading data from the memory 116 in any suitable manner.

[0021] In some embodiments, the battery monitoring circuitry 119 may be configured to determine a battery charging level of the battery 117 in the ultrasound device 102. In some embodiments, the battery monitoring circuitry 119 may be in the form of an integrated circuit

(IC) on a printed circuit board (PCB) in the ultrasound device 102. In some embodiments, the battery monitoring circuitry 119 may be referred to as a fuel gauge. In some embodiments, the battery monitoring circuitry 119 may also include battery charging circuitry.

[0022] In some embodiments, the temperature sensing circuitry 121 may be configured to determine a temperature in the interior of the ultrasound device 102. In some embodiments, the temperature sensing circuitry 121 may include a thermistor in the interior of the ultrasound device 102.

[0023] The inertial measurement unit (IMU) 123 may be configured to generate data regarding linear acceleration of the ultrasound device 102, data regarding angular velocity of the ultrasound device 102, and/or data regarding magnetic force acting on the ultrasound device 102 due to the local magnetic field, which in many cases is simply the field of the earth. The IMU 123 may include an accelerometer, a gyroscope, and/or a magnetometer. Depending on the sensors present in the IMU 123, the data generated by the IMU 123 may describe three degrees of freedom, six degrees of freedom, or nine degrees of freedom for the ultrasound device 102. For example, the IMU 123 may include an accelerometer, a gyroscope, and/or magnetometer. Each of these types of sensors may describe three degrees of freedom. If the IMU 123 includes one of these sensors, the IMU 123 may describe three degrees of freedom. If the IMU 123 includes two of these sensors, the IMU 123 may describe two degrees of freedom. If the IMU 123 includes three of these sensors, the IMU 123 may describe nine degrees of freedom. The ultrasound device 102 may transmit data to the processing device 104 over a wired (e.g., through a lightning connector or a mini-USB connector) and/or wireless (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols) communication link.

[0024] Referring now to the processing device 104, the processing device 104 may be configured, in general, to process the ultrasound data received from the ultrasound device 102 to generate ultrasound images for display on the display screen 118. The processing may be performed by, for example, the processor 120. The processor 120 may also be adapted to control the acquisition of ultrasound data with the ultrasound device 102. The ultrasound data may be processed in real-time during a scanning session as the echo signals are received. In some embodiments, the displayed ultrasound image may be updated at a rate of at least 5Hz, at least 10 Hz, at least 20Hz, at a rate between 5 and 60 Hz, or at a rate of more than 20 Hz. For example, ultrasound data may be acquired even as images are being generated based

on previously acquired data and while a live ultrasound image is being displayed. As additional ultrasound data is acquired, additional frames or images generated from more-recently acquired ultrasound data may be sequentially displayed. Additionally, or alternatively, the ultrasound data may be stored temporarily in a buffer during a scanning session and processed in less than real-time.

[0025] The processing device 104 may be configured to perform certain of the processes (e.g., the processes 5-6) described herein using the processor 120 and one or more articles of manufacture that include non-transitory computer-readable storage media such as the memory 122. The processor 120 may control writing data to and reading data from the memory 116 in any suitable manner. To perform certain of the processes described herein, the processor 120 may execute one or more processor-executable instructions stored in one or more non-transitory computer-readable storage media (e.g., the memory 122), which may serve as non-transitory computer-readable storage media storing processor-executable instructions for execution by the processor 120. The camera 126 may be configured to detect light (e.g., visible light) to form an image. The camera 126 may be on the same face of the processing device 104 as the display screen 118, or on the opposite face. The display screen 118 may be configured to display images and/or videos, and may be, for example, a liquid crystal display (LCD), a plasma display, and/or an organic light emitting diode (OLED) display on the processing device 104. The input device 124 may include one or more devices capable of receiving input from a user and transmitting the input to the processor 120. For example, the input device 124 may include a keyboard, a mouse, a microphone, touch-enabled sensors on the display screen 118, and/or a microphone. The speaker 128 may be configured to emit audio. The display screen 118, the input device 124, the camera 126, and the speaker 128 may be communicatively coupled to the processor 120 and/or under the control of the processor 120.

[0026] It should be appreciated that the processing device 104 may be implemented in any of a variety of ways. For example, the processing device 104 may be implemented as a handheld device such as a mobile smartphone or a tablet. Thereby, a user of the ultrasound device 102 may be able to operate the ultrasound device 102 with one hand and hold the processing device 104 with another hand. In other examples, the processing device 104 may be implemented as a portable device that is not a handheld device, such as a laptop. In yet other examples, the processing device 104 may be implemented as a stationary device such as a desktop computer.

[0027] In some embodiments, a party may provide from the server 108 to the processing device 104 processor-executable instructions for storing in one or more non-transitory computer-readable storage media (e.g., the memory 122) which, when executed, may cause the processing device 104 to perform certain of the processes (e.g., the processes 5-6) described herein. While not illustrated, in some embodiments the ultrasound device 102 may be connected to the network 106 over a wired connection (e.g., via an Ethernet cable) and a party may provide from the server 108 to the ultrasound device 102 processor-executable instructions for storing in one or more non-transitory computer-readable storage media (e.g., the memory 116) which, when executed, may cause the ultrasound device 102 to perform certain of the processes (e.g., the processes 7-9) described herein. Additionally or alternatively, a party may provide from the server 108 to the processing device 104 processor-executable instructions which the processing device 104 may provide to the ultrasound device 102 over a wired and/or wireless connection for storing in one or more non-transitory computer-readable storage media (e.g., the memory 116) which, when executed, may cause the ultrasound device 102 to perform certain of the processes (e.g., the processes 7-9) described herein.

[0028] The ultrasound system 100 may be configured for medical ultrasound imaging. In particular, the ultrasound device 102 may be designed and configured for medical ultrasound imaging. For example, the ultrasound device 102 may be configured to use presets optimized for medical ultrasound imaging of various anatomical structures and regions in people or animals.

[0029] FIG. 3 illustrates an example of a user 330, an ultrasound device 302, and a processing device 304, in accordance with certain embodiments described herein. The ultrasound device 302 may be the ultrasound device 102, and may be any of the ultrasound devices described herein. The processing device 304 may be the processing device 104, and may be any of the processing devices described herein. The user 330 has a right hand 334 and a left hand 332. A cable 336 extends between the ultrasound device 302 and the processing device 304. The processing device 304 and the ultrasound device 302 may be configured to be in operative communication with each other; in the example of FIG. 3, the communication may occur over the cable 336, which may be, for example, an Ethernet cable, a Universal Serial Bus (USB) cable, or a Lightning cable. It should be appreciated that in some embodiments, the ultrasound device 302 and the processing device 304 may communicate wirelessly, and the cable 336 may be absent.

[0030] The processing device 304 may be, for example, a mobile phone or tablet. It should be appreciated that the ultrasound device 302 and the processing device 304 are both handheld, in that both can be held by a person. Thus, the whole illustrated ultrasound system consisting of the ultrasound device 302, the processing device 304, and the cable 336, is handheld. In some embodiments, the processing device 304 may be a device more suited not to be handheld, such as a laptop, in which case the ultrasound device 302 may be handheld but the whole ultrasound system may not be considered handheld.

[0031] In FIG. 3, the user 330 holds the ultrasound device 302 in his/her right hand 334 and holds the processing device 304 in his/her left hand 332. However, it should be appreciated that the user 330 may hold the ultrasound device 302 in his/her left hand 332 and hold the processing device 304 in his/her right hand 334. In FIG. 3, the user 330 is scanning himself or herself. However, it should be appreciated that the user 330 may scan a different subject.

[0032] FIGs. 4A and 4B illustrate side and top views, respectively, of an example ultrasound device 402, in accordance with certain embodiments described herein. The ultrasound 402 may be the ultrasound device 102 and/or the ultrasound device 302, and may be any of the ultrasound devices described herein. FIGs. 4A and 4B further illustrate sizes L1, L2, and L3 representing the overall extent of the ultrasound device 302 at its widest part along each of its three dimensions. In some embodiments, L1 may be equal to or between approximately 25-45 mm. In some embodiments, L1 may be equal to or between approximately 30-40 mm. In some embodiments, L1 may be equal to approximately 35 mm. In some embodiments, L2 may be equal to or between approximately 105-170 mm. In some embodiments, L2 may be equal to or between approximately 115-160 mm. In some embodiments, L2 may be equal to or between approximately 125-150 mm. In some embodiments, L3 may be equal to or between approximately 35-70 mm. In some embodiments, L3 may be equal to or between approximately 40-65 mm. In some embodiments, L3 may be equal to or between approximately 45-60 mm.

[0033] In some embodiments, the weight of the ultrasound device 402 may be between or equal to approximately 260-280 gm. In some embodiments, the weight of the ultrasound device 402 may be between or equal to approximately 265-275 gm. In some embodiments, the weight of the ultrasound device 402 may be between or equal to approximately 260-270 gm. It should be appreciated that the above dimensions and weights may not include any cable attached to the ultrasound device 402.

[0034] FIGs. 5 and 6 illustrate example flow diagrams for processes 500 and 600,

respectively, for controlling an ultrasound device (e.g., the ultrasound devices 102, 302, and/or 402, some or all of which may be the same) to change from default mode to power save mode, in accordance with certain embodiments described herein. The process 500 may be performed by a processor (e.g., the processor 120) in a processing device (e.g., the processing device 104 or 304, which may be the same) that is in operative communication with the ultrasound device. The processing device may be, for example, a smartphone, tablet, or laptop. The processing device and the ultrasound device may communicate over a wired communication link (e.g., through an Ethernet cable, a Universal Serial Bus (USB) cable, or a Lightning cable) and/or over a wireless communication link (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols).

[0035] In act 502 of the process 500, the processing device receives, from the ultrasound device, an indication of a battery charging level of the ultrasound device. The ultrasound device includes a battery (e.g., the battery 117). In some embodiments, the ultrasound device may also include battery monitoring circuitry (e.g., the battery monitoring circuitry 119) configured to determine a battery charging level of the battery in the ultrasound device. In some embodiments, the battery monitoring circuitry may be in the form of an integrated circuit (IC) on a printed circuit board (PCB) in the ultrasound device. In some embodiments, the battery monitoring circuitry may be referred to as a fuel gauge. In some embodiments, the battery monitoring circuitry may also include battery charging circuitry. The ultrasound device may transmit an indication of the battery charging level (e.g., a digital signal encoding the battery charging level), as determined by the battery monitoring circuitry, to the processing device over a wired communication link (e.g., through an Ethernet cable, a Universal Serial Bus (USB) cable, or a Lightning cable) and/or over a wireless communication link (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols). The processing device may then receive the indication of the battery charging level from the ultrasound device over the communication link. The process 500 proceeds from act 502 to act 504.

[0036] In act 504, the processing device determines whether the battery charging level of the ultrasound device (an indication of which was received in act 502) is below a threshold battery charging level. In some embodiments, the threshold battery charging level may be a predetermined battery charging level. In some embodiments, the threshold battery charging level may be a user-defined battery charging level. If the processing device determines that the battery charging level of the ultrasound device is not below the threshold battery charging

level, the process 500 proceeds back to act 502. If the processing device determines that the battery charging level of the ultrasound device is below the threshold battery charging level, the process 500 proceeds to act 506.

[0037] In act 506, the processing device prompts a user whether to control the ultrasound device to change from default mode to power save mode. As described above, the process 500 proceeds to act 506 if the processing device determines that the battery charging level of the ultrasound device is below a threshold battery charging level. Thus, the processing device prompts the user whether to control the ultrasound device to change from default mode to power save mode based on the processing device determining that the battery charging level of the ultrasound device is below a threshold battery charging level. Changing from default mode to power save mode may help the ultrasound device to conserve power when its battery charging level is low (i.e., below the threshold). In some embodiments, the prompt may include text displayed on a display screen (e.g., the display screen 118) of the processing device. In some embodiments, the prompt may include graphics displayed on a display screen of the processing device. In some embodiments, the prompt may include audio outputted by a speaker (e.g., the speaker 128) of the processing device. The process 500 proceeds from act 506 to act 508.

[0038] In act 508, the processing device determines whether the user selected to control the ultrasound device to change from default mode to power save mode. In some embodiments, the processing device may determine whether the user selected an option on a display screen of the processing device (e.g., by touching an option displayed on a touch-sensitive display screen of the processing device). In some embodiments, the processing device may determine, using a microphone and audio processing software on the processing device, whether the user spoke a command to control the ultrasound device to change from default mode to power save mode. If the processing device determines that the user selected to control the ultrasound device to change from default mode to power save mode, then the process 500 proceeds to act 510. If the processing device determines that the user did not select to control the ultrasound device to change from default mode to power save mode, then the process 500 remains at act 508 and continues to determine whether the user selected to control the ultrasound device to change from default mode to power save mode.

[0039] In act 510, the processing device controls (based on the user's selection in act 508) the ultrasound device to change from default mode to power save mode. The processing device may control the ultrasound device to change from default mode to power save mode by

transmitting control signals to the ultrasound device over a wired communication link (e.g., through an Ethernet cable, a Universal Serial Bus (USB) cable, or a Lightning cable) and/or over a wireless communication link (e.g., using BLUETOOTH, ZIGBEE, and/or wiFi wireless protocols). For example, the processing device may transmit control signals to the ultrasound device that cause (e.g., as part of act 706) the ultrasound device to supply a control signal (e.g., the "power save mode" control signals in FIG. 2) to control circuitry (e.g., the control circuitry 230 in FIG. 2). Based on receiving the control signal, the control circuitry may cause the ultrasound device to change from default mode to power save mode by modifying one or more parameter values of ultrasound circuitry in the ultrasound device from default mode parameter values to power save mode parameter values. Further description of the ultrasound device changing from default mode to power save mode may be found with reference to FIG. 10.

[0040] In some embodiments, at act 504, the processing device may determine whether the battery charging level of the ultrasound device is below or equal to a threshold battery charging level. If the processing device determines that the battery charging level of the ultrasound device is below or equal to the threshold battery charging level, the process 500 proceeds to act 506; otherwise, the process 500 proceeds to act 502. In some embodiments, at act 504, the processing device may determine whether the battery charging level of the ultrasound device is above a threshold battery charging level. If the processing device determines that the battery charging level of the ultrasound device is above the threshold battery charging level, the process 500 proceeds to act 502; otherwise, the process 500 proceeds to act 506. In some embodiments, at act 504, the processing device may determine whether the battery charging level of the ultrasound device is above or equal to a threshold battery charging level. If the processing device determines that the battery charging level of the ultrasound device is above or equal to the threshold battery charging level, the process 500 proceeds to act 502; otherwise, the process 500 proceeds to act 506.

[0041] In some embodiments, acts 502, 504, and 506 may be absent. Thus, the user may select to control the ultrasound device to change from default mode to power save mode at any time, regardless of the battery charging level of the ultrasound device.

[0042] In some embodiments, acts 506 and 508 may be absent, and the process 500 may proceed from act 504 to act 510. Thus, the processing device may automatically control the ultrasound device to change from default mode to power save mode, without a user selection.

[0043] In act 602 of the process 600, the processing device receives, from the ultrasound

device, an indication of a temperature of the ultrasound device. In some embodiments, the ultrasound device may include temperature sensing circuitry (e.g., the temperature sensing circuitry 121) in the interior of the ultrasound device. In some embodiments, the temperature sensing circuitry may include a thermistor in the interior of the ultrasound device, and the indication of the temperature of the ultrasound device received by the processing device from the ultrasound device may be an indication of the temperature reading from that thermistor.

[0044] In some embodiments, the processing device may receive the indication of the temperature of the ultrasound device and process the indication. The result of such processing of the indication may be considered the temperature of the ultrasound device. In some embodiments, the temperature sensing circuitry may include multiple thermistors in the interior of the ultrasound device, and the indication of the temperature of the ultrasound device may be an indication of the temperature readings from the multiple thermistors. The processing device may calculate the average, median, maximum, or minimum of temperature readings from multiple thermistors inside the ultrasound device, and the result may be considered the temperature of the ultrasound device. In some embodiments, the processing device may calculate a running average of a time series of temperature readings from a thermistor, and the result may be considered the temperature of the ultrasound device. In some embodiments, the processing device may use a model that relates one or more temperature readings from thermistors inside the ultrasound device to the temperature of the external surface of the housing of the ultrasound device. Thus, the processing device may calculate the temperature of the external surface of the housing of the ultrasound device based on the one or more temperature readings from thermistors inside the ultrasound device, and the result of this calculation may be considered the temperature of the ultrasound device. In some embodiments, the ultrasound device itself may perform the processing described above, and the indication of the temperature of the ultrasound device received by the processing device from the ultrasound device may be the result of this processing.

[0045] The ultrasound device may transmit the indication of the temperature of the ultrasound device to the processing device over a wired communication link (e.g., through an Ethernet cable, a Universal Serial Bus (USB) cable, or a Lightning cable) and/or over a wireless communication link (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols). In some embodiments, the indication may be a digital signal directly encoding the temperature of the ultrasound device, such as when the indication is a digital signal encoding a temperature reading by a thermistor inside the ultrasound device, and the temperature of the

ultrasound device is that temperature reading. In some embodiments, the indication may be a digital signal encoding intermediate information from which the temperature of the ultrasound device may be derived, such as when the indication is a digital signal encoding one or more temperature readings by thermistors inside the ultrasound device, and the temperature of the ultrasound device is a temperature of the external surface of the housing of the ultrasound device which may derived, using a model, from the temperature readings by the thermistors inside the ultrasound device. The processing device may then receive the indication of the temperature from the ultrasound device over the communication link. The process 600 proceeds from act 602 to act 604.

[0046] In act 604, the processing device determines whether the temperature of the ultrasound device (an indication of which was received in act 602) is above a threshold temperature. In some embodiments, the threshold temperature may be a predetermined temperature. In some embodiments, the threshold temperature may be a user-defined temperature. If the processing device determines that the temperature of the ultrasound device is not above the threshold temperature, the process 600 proceeds back to act 602. If the processing device determines that the temperature of the ultrasound device is above the threshold temperature, the process 600 proceeds to act 606. Acts 606, 608, and 610 are the same as acts 506. 508, and 510, respectively.

[0047] In some embodiments, at act 604, the processing device may determine whether the temperature of the ultrasound device is above or equal to a threshold temperature. If the processing device determines that the temperature of the ultrasound device is above or equal to the threshold temperature, the process 600 proceeds to act 606; otherwise, the process 600 proceeds to act 602. In some embodiments, at act 604, the processing device may determine whether the temperature of the ultrasound device is below a threshold temperature. If the processing device determines that the temperature of the ultrasound device is below the threshold temperature, the process 600 proceeds to act 602; otherwise, the process 600 proceeds to act 606. In some embodiments, at act 604, the processing device may determine whether the temperature of the ultrasound device is below or equal to a threshold temperature. If the processing device determines that the temperature of the ultrasound device is below or equal to the threshold temperature, the process 600 proceeds to act 602; otherwise, the process 600 proceeds to act 606.

[0048] In some embodiments, acts 602, 604, and 606 may be absent. Thus, the user may select to control the ultrasound device to change from default mode to power save mode at

any time, regardless of the temperature of the ultrasound device.

[0049] In some embodiments, acts 606 and 608 may be absent, and the process 600 may proceed from act 604 to act 610. Thus, the processing device may automatically control the ultrasound device to change from default mode to power save mode, without a user selection.

[0050] FIG. 7 illustrates an example flow diagram for a process 700 for an ultrasound device (e.g., the ultrasound devices 102, 302, and/or 402, all or some of which may be the same) changing from default mode to power save mode, in accordance with certain embodiments described herein. The process 700 may be performed by control circuitry (e.g., the control circuitry 230) in an ultrasound device that is in operative communication with a processing device (e.g., the processing device 104 and/or 304, which may be the same). The processing device may be, for example, a smartphone, tablet, or laptop. The processing device and the ultrasound device may communicate over a wired communication link (e.g., through an Ethernet cable, a Universal Serial Bus (USB) cable, or a Lightning cable) and/or over a wireless communication link (e.g., using BLUETOOTH, ZIGBEE, and/or WiFi wireless protocols).

[0051] In act 702, an ultrasound device determines an anatomical region type of a subject that is being analyzed by the ultrasound device. In some embodiments, for example, an ultrasound device receives a control signal identifying one or more anatomical regions undergoing an analysis. In particular, the anatomical region type may be determined by a user's selection provided to a processing device (e.g., using an interface in a smartphone). On the other hand, a processing device or the ultrasound device may automatically determine a particular anatomical region type based on ultrasound data and other data. Examples of different anatomical region types of a subject may include an abdomen, a bladder, a lung, a nerve, multiple vascular types, a musculoskeletal type, or a cardiac type. Likewise, anatomical region types may be organized according to subtypes, such as a regular abdomen scan or a deep abdomen scan.

[0052] Furthermore, depending on the determination of a particular anatomical region type, different power save modes may be applied to an ultrasound transducer array and other ultrasound circuitry. For example, an ultrasound scan of a bladder of a living subject in one power save mode may require less electrical power consumption than a power save mode for an ultrasound scan of an abdomen.

[0053] In some embodiments, a processing device or an ultrasound device includes a view classifier that determines an anatomical region type based on ultrasound data. For example, a

view classifier may use a machine-learning model, such as one or more trained artificial neural networks. More specifically, an artificial neural network may be a convolutional neural network that obtains one or more ultrasound images as inputs in order to recognize an anatomical region in the one or more ultrasound images. Thus, a view classifier may use a machine-learning algorithm (such as a supervised learning algorithm) to predict a label for an anatomical region corresponding to the ultrasound data. For illustration, a view classifier may recognize whether an anatomical region in an image represents an apical four chamber or apical two chamber view of the heart. Thus, the anatomical region type determination may be automated using various machine-learning models and machine-learning techniques, such as convolutional neural networks, a recurrent neural network (e.g., a long short-term memory (LSTM) network), a random forest, a support vector machine, a linear classifier, and/or various statistical techniques. In some embodiments, the view classifier may be stored on the processing device. In some embodiments, the processing device may access a machine-learning model on an external electronic device (e.g., a server).

[0054] In act 704, the ultrasound device receives, from the processing device, a command to change from default mode to a power save mode associated with the anatomical region. For example, the command may be received as part of acts 510 and/or 610. As will described below, there may be multiple power save modes, each associated with a particular anatomical region. The process 700 proceeds from act 704 to act 706. In act 706, the ultrasound device changes from default mode to the power save mode associated with the anatomical region. For example, the ultrasound device may supply a control signal (e.g., the "power save mode" control signals in FIG. 2) to control circuitry (e.g., the control circuitry 230 in FIG. 2). Based on receiving the control signal, the control circuitry may cause the ultrasound device to change from default mode to power save mode by modifying one or more parameter values of ultrasound circuitry in the ultrasound device. Further description of the ultrasound device changing from default mode to power save mode may be found with reference to FIG. 10.

[0055] FIGs. 8-9 illustrate example flow diagrams for processes 800 and 900, respectively, for an ultrasound device (e.g., the ultrasound devices 102, 302, and/or 402, all or some of which may be the same) changing from default mode to power save mode, in accordance with certain embodiments described herein. The processes 800 and 900 may be performed by control circuitry in an ultrasound device.

[0056] In act 804 of the process 800, the ultrasound device determines whether the battery charging level of the ultrasound device is below a threshold battery charging level. Further

description of determining the battery charging level of the ultrasound device may be found with reference to the process 500. The process 800 proceeds from act 804 to act 806.

[0057] In act 804, the ultrasound device prompts a user whether to control the ultrasound device to change from default mode to power save mode. As described above, the process 800 proceeds to act 806 if the processing device determines that the battery charging level of the ultrasound device is below a threshold battery charging level. Thus, the ultrasound device prompts the user whether to control the ultrasound device to change from default mode to power save mode based on the ultrasound device determining that the battery charging level of the ultrasound device is below a threshold battery charging level. Changing from default mode to power save mode may help the ultrasound device to conserve power when its battery charging level is low (i.e., below the threshold). In some embodiments, the prompt may include an indicator on the ultrasound device (e.g., a light-emitting diode) turning on or off. In some embodiments, the prompt may include text displayed on a display screen of the ultrasound device. In some embodiments, the prompt may include graphics displayed on a display screen of the ultrasound device. In some embodiments, the prompt may include audio outputted by a speaker of the ultrasound device. The process 800 proceeds from act 806 to act 808.

[0058] In act 808, the ultrasound device determines whether the user selected to control the ultrasound device to change from default mode to power save mode. In some embodiments, the ultrasound device may determine whether the user pressed a button on the ultrasound device. In some embodiments, the ultrasound device may determine whether the user selected an option on a display screen of the ultrasound device (e.g., by touching an option displayed on a touch-sensitive display screen of the ultrasound device). In some embodiments, the ultrasound device may determine, using a microphone and audio processing software on the ultrasound device, whether the user spoke a command to control the ultrasound device to change from default mode to power save mode. If the ultrasound device determines that the user selected to control the ultrasound device to change from default mode to power save mode, then the process 800 proceeds to act 810. If the ultrasound device determines that the user did not select to control the ultrasound device to change from default mode to power save mode, then the process 800 remains at act 808 and continues to determine whether the user selected to control the ultrasound device to change from default mode to power save mode. Act 810 is the same as act 706, in which the ultrasound device changes from default mode to power save mode.

[0059] In some embodiments, at act 804, the ultrasound device may determine whether the battery charging level of the ultrasound device is below or equal to a threshold battery charging level. If the ultrasound device determines that the battery charging level of the ultrasound device is below or equal to the threshold battery charging level, the process 800 proceeds to act 806; otherwise, the process 800 proceeds to act 802. In some embodiments, at act 804, the ultrasound device may determine whether the battery charging level of the ultrasound device is above a threshold battery charging level. If the ultrasound device determines that the battery charging level of the ultrasound device is above the threshold battery charging level, the process 800 proceeds to act 802; otherwise, the process 800 proceeds to act 806. In some embodiments, at act 804, the ultrasound device may determine whether the battery charging level of the ultrasound device is above or equal to a threshold battery charging level. If the ultrasound device determines that the battery charging level of the ultrasound device is above or equal to the threshold battery charging level, the process 800 proceeds to act 802; otherwise, the process 800 proceeds to act 806.

[0060] In some embodiments, acts 804 and 806 may be absent. Thus, the user may select to control the ultrasound device to change from default mode to power save mode at any time, regardless of the battery charging level of the ultrasound device.

[0061] In some embodiments, acts 806 and 808 may be absent, and the process 800 may proceed from act 804 to act 810. Thus, the ultrasound device may automatically control the ultrasound device to change from default mode to power save mode, without a user selection.

[0062] In act 904 of the process 900, the ultrasound device determines whether the temperature of the ultrasound device is above a threshold temperature. Further description of determining the temperature of the ultrasound device may be found with reference to the process 600. The process 900 proceeds from act 904 to act 906. Acts 906, 908, and 910 are the same as acts 806, 808, and 810, respectively.

[0063] In some embodiments, at act 904, the ultrasound device may determine whether the temperature of the ultrasound device is above or equal to a threshold temperature. If the ultrasound device determines that the temperature of the ultrasound device is above or equal to the threshold temperature, the process 900 proceeds to act 906; otherwise, the process 900 proceeds to act 904. In some embodiments, at act 904, the ultrasound device may determine whether the temperature of the ultrasound device is below a threshold temperature. If the ultrasound device determines that the temperature of the ultrasound device is below the threshold temperature, the process 900 proceeds to act 904; otherwise, the process 900

proceeds to act 906. In some embodiments, at act 904, the ultrasound device may determine whether the temperature of the ultrasound device is below or equal to a threshold temperature. If the ultrasound device determines that the temperature of the ultrasound device is below or equal to the threshold temperature, the process 900 proceeds to act 904; otherwise, the process 900 proceeds to act 906.

[0064] In some embodiments, acts 904 and 906 may be absent. Thus, the user may select to control the ultrasound device to change from default mode to power save mode at any time, regardless of the temperature of the ultrasound device.

[0065] In some embodiments, acts 906 and 908 may be absent, and the process may proceed from act 904 to act 910. Thus, the ultrasound device may automatically control the ultrasound device to change from default mode to power save mode, without a user selection.

[0066] FIG. 10 illustrates an ultrasound transducer array 1034 of an ultrasound device, in accordance with certain embodiments described herein. The ultrasound transducer array 1034 includes M ultrasound transducers 1002 along the azimuthal dimension 1036 of the ultrasound transducer array 1034 and N ultrasound transducers 1002 along the elevational dimension 1038 of the ultrasound transducer array 1034, where $M > N$. Each of the ultrasound transducers 1002 may be coupled to ultrasound circuitry (which may include, for example, at least some or all of the ultrasound circuitry 200 described below) configured to process ultrasound signals from the ultrasound transducer 1002 to which it is coupled.

[0067] FIG. 2 illustrates an ultrasound transducer (or, in some embodiments, multiple ultrasound transducers coupled together) 1002 and ultrasound circuitry 200 in an ultrasound device, in accordance with certain embodiments described herein. In some embodiments, the ultrasound circuitry 200 may be integrated circuitry. The ultrasound transducer 1002 may be configured to transmit ultrasound signals and to produce electrical current signals representing received ultrasound signals. The ultrasound transducer 1002 may be a capacitive micromachined ultrasound transducer (CMUT) in some embodiments. In other embodiments, the ultrasound transducer 1002 may be a piezoelectric micromachined ultrasound transducer (PMUTs). Alternative types of ultrasound transducers may also be used in other embodiments. The ultrasound transducer 1002 may be a portion of the ultrasound transducers in the ultrasound transducer array 1034.

[0068] The ultrasound circuitry 200 includes transmit circuitry 201 and receive circuitry 203. The transmit circuitry 201 may be configured to cause transmission of ultrasound signals by the ultrasound transducer 1002. The transmit circuitry 201 includes a waveform generator

206 coupled to a pulser 208. The pulser 208 may be configured to drive the ultrasound transducer 1002 to emit ultrasound signals. The waveform generator 206 may be configured to control the pulser 208 to cause the ultrasound transducer 1002 to emit ultrasound signals having particular waveforms.

[0069] The receive circuitry 203 may be configured to process electrical signals representing ultrasound signals received by the ultrasound transducer 1002. The receive circuitry 203 includes a receive switch 210, amplifiers, and an ADC 226. The amplifiers include a transimpedance amplifier (TIA) 212, an averaging circuit 214, an amplifier 216b in an auto-zero block 216, a time gain compensation circuit (218), analog-to-digital converter (ADC) drivers 224, and an ADC 226. The receive circuitry 203 includes other circuitry not explicitly illustrated, such as other receive switches, TIAs, averaging circuits, auto-zero blocks, time gain compensation circuits, ADC drivers, and ADCs configured to process signals from other ultrasound transducers not explicitly illustrated in FIG. 2.

[0070] The receive switch 210 may be configured to open when the ultrasound transducer 1002 is transmitting ultrasound signals, thus decoupling the pulser 208 from the receive circuitry 203 during transmit events. The receive switch 210 may be configured to close when the ultrasound transducer 1002 is receiving ultrasound signals, thus coupling the pulser 208 to the receive circuitry 203 during receive events and allowing electrical current signals representing ultrasound signals received by the ultrasound transducer 1002 to be processed by the receive circuitry 203. The transimpedance amplifier 212 may be configured to convert the electrical current signals to voltage signals for processing by the receive circuitry 203.

[0071] The averaging circuit 214 may also be referred to as a summer or a summing amplifier. In some embodiments, the averaging circuit 214 may be a buffer or an amplifier. The averaging circuit 214 may be configured to receive output signals from the transimpedance amplifier 212 and one or more other transimpedance amplifiers in the receive circuitry 203 (not explicitly illustrated) and provide an averaged output signal. The averaged output signal may be formed in part by adding or subtracting the signals from the various transimpedance amplifiers. The averaging circuit 214 may include, for example, a variable feedback resistance, the value of which may be adjusted dynamically based upon the number of transimpedance amplifiers from which the averaging circuit 214 receives signals.

[0072] The averaging circuit 214 is coupled to the auto-zero block 216. Although not specifically depicted as such, the auto-zero block 216 may be configured to receive a differential input signal and remove an DC offset. The auto-zero block 216 includes one or

more capacitors 216a as well as an amplifier 216b, which may be configured to reset the DC level after the capacitors 216a.

[0073] The output of the auto-zero block 216 is coupled to the time gain compensation (TGC) circuit 218. In the example shown, the TGC circuit 218 includes a variable attenuator 220 and a fixed gain amplifier 222. The TGC circuit 218 may be configured to vary the gain applied signals being processed by the receive circuitry 203 as a function of time, to account for attenuation of ultrasound signals by tissue.

[0074] The output of the TGC circuit 218 is coupled to the analog-to-digital converter (ADC) 226 via ADC drivers 224. In the illustrated example, the ADC drivers 224 include a first ADC driver 225a and a second ADC driver 225b, although in some embodiments there may be more than two ADC drivers 224 or fewer. The ADC 226 may be configured to digitize the analog signal(s) from the TGC circuit 218.

[0075] The bias generator 228 (which in some embodiments may be one or more bias generators 228) may be configured to supply bias currents to the amplifiers in the ultrasound circuitry 203 , including the TIA 212, the averaging circuit 214, the amplifier 216b of the auto-zero block 216, the variable attenuator 220, the fixed gain amplifier 222, the first ADC driver 225a, and the second ADC driver 225b. This is illustrated generally by the connections labeled "bias" from the bias generator 228 to these circuit components, although it should be appreciated that the specific bias current supplied by the bias generator 228 to each circuit component may be different. The bias generator 228 and the waveform generator 206 are controlled by control circuitry 230, illustrated generally by the control signals "ctrl" outputted by the control circuitry 230 to the bias generator 228 and the waveform generator 206.

[0076] It should be appreciated that the ultrasound circuitry 200 of the ultrasound device may include further instances (not illustrated) of transmit circuitry 201 and receive circuitry 203 coupled to other ultrasound transducers 1002 in the ultrasound transducer array 1034. It should be appreciated that the ultrasound transducers 1002 of the ultrasound transducer array 1034 and the ultrasound circuitry 200 may be located on a single substrate or on different substrates. For example, the ultrasound transducers 1002 and some or all of the ultrasound circuitry 200 may be monolithically integrated on the same semiconductor die. Such integration may be facilitated by using CMUTs as the ultrasound transducers 1002. The components of FIG. 2 form part of the ultrasound device, which may be, for example, a handheld ultrasound probe device or an ultrasound patch configured to be worn by a patient.

[0077] It should be appreciated that there may be multiple instances of the receive circuitry 203, each instance configured to process signals from a portion of the ultrasound transducers 1002 in the ultrasound transducer array 1034. In some embodiments, there may be greater than one thousand instances of the receive circuitry 203 in an ultrasound device. In some embodiments, all or a portion of all the instances of the receive circuitry 203 in an ultrasound device may be integrated circuitry. In some embodiments, all or a portion of all the instances of the receive circuitry 203 in an ultrasound device may be integrated circuitry that is integrated on a semiconductor chip. There may also be multiple instances of the transmit circuitry 201, each instance configured to cause a portion of the ultrasound transducers 1002 in the ultrasound transducer array 1034 to transmit ultrasound signals.

[0078] In some embodiments, when the ultrasound device changes from default mode to power save mode (e.g., at acts 706, 810, and/or 910), the control circuitry 230 may receive a control signal (labelled in FIG. 2 as "power save mode") to change from default mode to power save mode. Based on receiving that control signal, the control circuitry 230 may control (e.g., using the control signal "ctrl") the bias generator 228 to change "bias" in order to reduce one or more of the bias currents supplied to one or more of the amplifiers in the receive circuitry 203, for example, one or more of the TIA 212, the averaging circuit 214, the amplifier 216b of the auto-zero block 216, the variable attenuator 220, the fixed gain amplifier 222, the first ADC driver 225a, and the second ADC driver 225b. In some embodiments, the bias generator 228 may be configured to supply at least three different levels of bias currents to these circuit components. For example, there may be three levels of bias currents, low, medium, and high. It should be appreciated that other numbers of levels of percentage differences may be used. When changing from default mode to power save mode, the control circuitry 230 may control the bias generator 228 to reduce the bias current level from a default mode bias current level to a lower bias current level. The default mode bias current level and the power save mode bias current level may be different for different presets, where a preset is a set of imaging parameter values for configuring the ultrasound device that are optimized for imaging a particular anatomical region(s) or structure(s). In other words, the control circuitry 230 may modify the bias current level parameter values in power save mode differently for different presets. Table 1 lists example default mode bias current levels and power save mode bias current levels for different presets:

Preset	Default Mode Bias Current Level	Power Save Mode Bias Current Level
Abdomen	Medium	Low
Abdomen Deep	Medium	Low
Aorta & Gallbladder	Medium	Low
Bladder	Medium	Low
Cardiac	Medium	Low
FAST	Medium	Low
Lung	Medium	Low
MSK-Soft Tissue	High	Low
Musculoskeletal	High	Low
Nerve	Low	Low
OB 1/GYN	Medium	Low
OB 2/3	Medium	Low
Pediatric Abdomen	Medium	Low
Pediatric Cardiac	Medium	Low
Pediatric Lung	Medium	Low
Small Organ	High	Low
Vascular: Access	Medium	Low
Vascular: Carotid	Medium	Low
Vascular: Deep Vein	Medium	Low
Cardiac Deep	Medium	Low

Table 1: Example default mode bias current levels and power save mode bias current levels for different presets

[0079] In some embodiments, reducing the bias currents from high level to low level may involve reducing the bias currents by a percentage in the range of approximately 20 % – 60%. (As referred to herein, reducing by a percentage X% means that the new value is (1-X/100) times the old value). In some embodiments, reducing the bias currents from high level to low level may involve reducing the bias currents by a percentage in the range of approximately 20 % – 30%. In some embodiments, reducing the bias currents from high level to low level may involve reducing the bias currents by a percentage in the range of approximately 30 % – 40%. In some embodiments, reducing the bias currents from high level to low level may involve reducing the bias currents by a percentage in the range of

approximately 40 % – 50%. In some embodiments, reducing the bias currents from high level to low level may involve reducing the bias currents by a percentage in the range of approximately 50 % – 60%. In various embodiments, the bias currents supplied at the low level may be approximately 20%, 22.5%, 25%, 27.5%, 30%, 32.5%, 35%, 37.5%, 40%, 42.5%, 45%, 47.5%, 50%, 52.5%, 55%, 57.5%, or 60% less than the bias currents supplied at the high level.

[0080] In some embodiments, reducing the bias currents from medium level to low level may involve reducing the bias currents by a percentage in the range of approximately 2.5 % – 40%. In some embodiments, reducing the bias currents from medium level to low level may involve reducing the bias currents by a percentage in the range of approximately 2.5 % – 10%. In some embodiments, reducing the bias currents from medium level to low level may involve reducing the bias currents by a percentage in the range of approximately 10 % – 20%. In some embodiments, reducing the bias currents from medium level to low level may involve reducing the bias currents by a percentage in the range of approximately 20 % – 30%. In some embodiments, reducing the bias currents from medium level to low level may involve reducing the bias currents by a percentage in the range of approximately 30 % – 40%. In various embodiments, the bias currents supplied at the low level may be approximately 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5%, 25%, 27.5%, 30%, 32.5%, 35%, 37.5%, or 40% less than the bias currents supplied at the medium level.

[0081] FIG. 11 illustrates a portion of the ultrasound circuitry 200 in more detail, in accordance with certain embodiments described herein. FIG. 11 illustrates ultrasound transducers 1002a – 1002h, receive switches 210a – 210h, multiplexing circuitry 1132, and TIAs 212a – 212h. The receive switches 210a – 210h are coupled between the ultrasound transducers 1002a – 1002h, respectively, and the multiplexing circuitry 1132. The multiplexing circuitry 1132 is coupled between the receive switches 210a – 210h and the TIAs 212a – 212h. The ultrasound transducer 1002, the receive switch 210, and the TIA 212 in FIG. 2 may represent, for example, the ultrasound transducer 1002a, the receive switch 210a, and the TIA 212a.

[0082] The multiplexing circuitry 1132 may be configured to couple certain of the ultrasound transducers 1002a – 1002h to certain of the TIAs 212a – 212h (when the corresponding receive switches 210a – 210h are closed). In other words, the multiplexing circuitry 1132 may be configured to couple a certain number (e.g., 1, 2, 4, or 8) of the ultrasound transducers 1002a – 1002h to each of certain of the TIAs 212a – 212h. For example, in one

configuration ("1x configuration"), the multiplexing circuitry 1132 may couple one ultrasound transducer 1002 to one TIA 212. For example, the multiplexing circuitry 1132 may couple the ultrasound transducer 1002a to the TIA 212a, the ultrasound transducer 1002b to the TIA 212b, the ultrasound transducer 1002c to the TIA 212c, the ultrasound transducer 1002d to the TIA 212d, the ultrasound transducer 1002e to the TIA 212e, the ultrasound transducer 1002f to the TIA 212f, the ultrasound transducer 1002g to the TIA 212g, and the ultrasound transducer 1002h to the TIA 212h. In another configuration ("2x configuration"), the multiplexing circuitry 1132 may couple two ultrasound transducers 1002 to one TIA 212. For example, the multiplexing circuitry 1132 may couple the ultrasound transducers 1002a – 1002b to the TIA 212a, the ultrasound transducers 1002c – 1002d to the TIA 212b, the ultrasound transducers 1002e – 1002f to the TIA 212c, and the ultrasound transducers 1002g – 1002h to the TIA 212d. The TIAs 212e – 212h may be turned off, thus conserving power compared to the 1x configuration. In another configuration ("4x configuration"), the multiplexing circuitry 1132 may couple four ultrasound transducers 1002 to one TIA 212. For example, the multiplexing circuitry 1132 may couple the ultrasound transducers 1002a – 1002d to the TIA 212a and the ultrasound transducers 1002e – 1002h to the TIA 212b. The TIAs 212c – 212h may be turned off, thus conserving power compared to the 2x configuration. In another configuration ("8x configuration"), the multiplexing circuitry 1132 may couple eight ultrasound transducers 1002 to one TIA 212. For example, the multiplexing circuitry 1132 may couple the ultrasound transducers 1002a – 1002h to the TIA 212a. The TIAs 212b – 212h may be turned off, thus conserving power compared to the 4x configuration. it should be appreciated that in some embodiments, there may be more or fewer ultrasound transducers 1002 than 8 per channel, and there may be different numbers of ultrasound transducers 1002 coupled by the multiplexing circuitry 1132 to each 212 in the different configurations. The control circuitry 230 may output control signals (labelled in FIG. 11 generally as "ctrl") to the multiplexing circuitry 1132 and to the TIAs 212 that may control which ultrasound transducers 1002 are coupled to which TIAs 212 and which TIAs 212 are turned off.

[0083] In some embodiments, the ultrasound transducers 1002a – 1002h may be arranged in a column along the elevational dimension 1038 of the ultrasound transducer array 1034 of the ultrasound device, where the column of ultrasound transducers 1002a – 1002h is located at a particular position along the azimuthal dimension 1036 of the ultrasound transducer array 1034. Coupling multiple ultrasound transducers 1002 in a column (i.e., at a particular

position along the azimuthal dimension 1036 of the ultrasound transducer array 1034) to one TIA 212 may be referred to as column summing. The different configurations described above may be referred to as column summing configurations.

[0084] As described above, coupling more ultrasound transducers 1002 to certain TIAs 212 may allow other TIAs 212 to be turned off, thus conserving power. On the other hand, coupling more ultrasound transducers 1002 to one TIA 212 may result in increased noise. In some embodiments, when the ultrasound device changes from default mode to power save mode (e.g., at acts 706, 810, and/or 910), the control circuitry 230 may receive a control signal (labelled in FIG. 2 as "power save mode") to change from default mode to power save mode. Based on receiving that control signal, the control circuitry 230 may control (e.g., using the control signals "ctrl") the multiplexing circuitry 1132 to increase the amount of column summing performed by increasing the number of ultrasound transducers 1002 coupled to certain TIAs 212, and to turn off other TIAs 212. The default mode column summing configuration and the power save mode column summing configuration may be different for different presets. In other words, the control circuitry 230 may modify the column summing parameter value in power save mode differently for different presets. Table 2 lists example default mode column summing configurations and power save mode column summing configurations for different presets. It should be appreciated that, in the example of Table 2, for those presets that have different default mode and power save mode column summing configurations, the power save mode column configuration includes increasing the number of ultrasound transducers 1002 coupled to TIAs by two times, although some presets in the example are increased from 1x to 2x, some from 2x to 4x, and some from 4x to 8x. In other embodiments, the power save mode column configuration includes increasing the number of ultrasound transducers 1002 coupled to TIAs by a different multiple than two.

Preset	Default Mode Column Summing Configuration	Power Save Mode Column Summing Configuration
Abdomen	2x	4x
Abdomen Deep	2x	4x
Aorta & Gallbladder	4x	8x
Bladder	2x	4x
Cardiac	1x	2x
FAST	2x	4x
Lung	1x	2x

MSK-Soft Tissue	1x	1x
Musculoskeletal	1x	1x
Nerve	1x	1x
OB 1/GYN	2x	4x
OB 2/3	2x	4x
Pediatric Abdomen	2x	4x
Pediatric Cardiac	1x	2x
Pediatric Lung	1x	2x
Small Organ	1x	1x
Vascular: Access	1x	1x
Vascular: Carotid	1x	2x
Vascular: Deep Vein	1x	1x
Cardiac Deep	2x	4x

Table 2: Example default mode column summing configurations and power save mode column summing configurations for different presets:

[0085] Referring back to FIG. 10, the set of ultrasound transducers 1002 from which ultrasound signals are processed may be referred to as the aperture. In some embodiments, multiple instances of receive circuitry 203 coupled to particular ultrasound transducers 1002 in the ultrasound transducer array 1034 may be turned off, and ultrasound signals from those ultrasound transducers 1002 may not be processed. Powering down the receive circuitry may reduce power, but may also reduce the size of the aperture.

[0086] As examples, the aperture may be reduced along the elevational dimension 1038 by powering down receive circuitry coupled to ultrasound transducers 1002 in certain rows along the elevational dimension 1038 of the ultrasound transducer array 1034. As specific examples, if the receive circuitry coupled to the ultrasound transducers 1002 in the outer N / 4 rows at both ends of the elevational dimension 1038 are turned off, then the aperture may be reduced to 1/2 of the size of the full aperture along the elevational dimension 1038. If the receive circuitry coupled to the ultrasound transducers 1002 in the outer 3N / 8 rows at both ends of the elevational dimension 1038 are turned off, then the aperture may be reduced to 1/4 of the size of the full aperture along elevational dimension 1038. The aperture may be reduced along the azimuthal dimension 1036 in a similar manner, by powering down receive circuitry coupled to ultrasound transducers 1002 in certain columns along the azimuthal

dimension 1036. The size of the aperture along the elevational dimension 1038 of the ultrasound transducer array 1034 may be referred to herein as the size of the elevational aperture and the size of the aperture along the azimuthal dimension 1036 of the ultrasound transducer array 1034 may be referred to herein as the size of the azimuthal aperture.

[0087] Referring back to FIG. 2, in some embodiments, when the ultrasound device changes from default mode to power save mode (e.g., at acts 706, 810, and/or 910), the control circuitry 230 may receive a control signal (labelled in FIG. 2 as "power save mode") to change from default mode to power save mode. Based on receiving that control signal, the control circuitry 230 may control (e.g., using the control signals "ctrl") the bias generator 228 to change "bias" in order to turn off multiple instances of receive circuitry 203 (i.e., amplifiers (e.g., the TIA 212, the averaging circuit 214, the amplifier 216b in the auto-zero block 216, the variable attenuator 220, the fixed gain amplifier 222, the first ADC driver 225a, the second ADC driver 225b) and the ADC 226) coupled to certain ultrasound transducers 1002, such that size of the elevational aperture and/or the size of the azimuthal aperture are reduced, in the manner described above. In some embodiments, the change between the default mode size of the elevational aperture and the size of the elevational aperture in power save mode may be different for different presets. In some embodiments, the change between the default mode size of the azimuthal aperture and the size of the azimuthal aperture in power save mode may be different for different presets. In other words, the control circuitry 230 may modify the elevational aperture and/or the azimuthal aperture parameter values in power save mode differently for different presets. Table 3 lists example default mode elevational aperture sizes and sizes of the elevational aperture in power save mode, for different presets:

Preset	Default Mode Elevational Aperture Size (mm)	Power Save Mode Elevational Aperture Size (mm)	Percentage Difference
Abdomen	6.656	3.328	50
Abdomen Deep	6.656	3.328	50
Aorta & Gallbladder	13.312	9.984	25
Bladder	6.656	3.328	50
Cardiac	9.984	6.656	33.33333333
FAST	6.656	3.328	50

Lung	3.328	3.328	0
MSK-Soft Tissue	3.328	3.328	0
Musculoskeletal	3.328	3.328	0
Nerve	3.328	3.328	0
OB 1/GYN	6.656	3.328	50
OB 2/3	9.984	6.656	33.33333333
Pediatric Abdomen	3.328	3.328	0
Pediatric Cardiac	6.656	3.328	50
Pediatric Lung	3.328	3.328	0
Small Organ	3.328	3.328	0
Vascular: Access	3.328	3.328	0
Vascular: Carotid	3.328	3.328	0
Vascular: Deep Vein	3.328	3.328	0
Cardiac Deep	9.984	6.656	33.33333333

Table 3: Example default mode elevational aperture sizes and sizes of the elevational aperture in power save mode, for different presets.

[0088] While Table 3 lists particular percentage reductions, in some embodiments, the elevational aperture size may be reduced by other percentages in the range of approximately 25% - 50%. In some embodiments, the elevational aperture size may be reduced by other percentages in the range of approximately 25% - 50%. In some embodiments, the elevational aperture size may be reduced by a percentage in the range of approximately 25% - 30%. In some embodiments, the elevational aperture size may be reduced by a percentage in the range of approximately 30% - 35%. In some embodiments, the elevational aperture size may be reduced by a percentage in the range of approximately 35% - 40%. In some embodiments, the elevational aperture size may be reduced by a percentage in the range of approximately 40% - 45%. In some embodiments, the elevational aperture size may be reduced by a percentage in the range of approximately 45% - 50%.

[0089] Table 4 lists example default mode azimuthal aperture sizes and sizes of the azimuthal aperture in power save mode, for different presets:

Preset	Default Mode Azimuthal Aperture Size (mm)	Power Save Mode Azimuthal (mm) Aperture Size	Percentage Difference
Abdomen	28.288	23.288	17.67533937
Abdomen Deep	28.288	23.288	17.67533937
Aorta & Gallbladder	28.288	23.288	17.67533937
Bladder	28.288	23.288	17.67533937
Cardiac	20	15	25
FAST	28.288	23.288	17.67533937
Lung	13	8	38.46153846
MSK-Soft Tissue	28.288	23.288	17.67533937
Musculoskeletal	28.288	23.288	17.67533937
Nerve	28.288	23.288	17.67533937
OB 1/GYN	28.288	23.288	17.67533937
OB 2/3	28.288	23.288	17.67533937
Pediatric Abdomen	28.288	23.288	17.67533937
Pediatric Cardiac	28.288	23.288	17.67533937
Pediatric Lung	28.288	23.288	17.67533937
Small Organ	28.288	23.288	17.67533937
Vascular: Access	28.288	23.288	17.67533937
Vascular: Carotid	28.288	23.288	17.67533937
Vascular: Deep Vein	28.288	23.288	17.67533937
Cardiac Deep	28.288	23.288	17.67533937

Table 4: Example default mode azimuthal aperture sizes and sizes of the azimuthal aperture in power save mode, for different presets.

[0090] While Table 4 lists particular percentage reductions, in some embodiments, the

azimuthal aperture size may be reduced by other percentages in the range of approximately 15% - 40%. In some embodiments, the azimuthal aperture size may be reduced by a percentage in the range of approximately 15% - 20%. In some embodiments, the azimuthal aperture size may be reduced by a percentage in the range of approximately 20% - 25%. In some embodiments, the azimuthal aperture size may be reduced by a percentage in the range of approximately 25% - 30%. In some embodiments, the azimuthal aperture size may be reduced by a percentage in the range of approximately 30% - 35%. In some embodiments, the azimuthal aperture size may be reduced by a percentage in the range of approximately 35% - 40%.

[0091] In some embodiments, when the ultrasound device changes from default mode to power save mode (e.g., at acts 706, 810, and/or 910), the control circuitry 230 may receive a control signal (labelled in FIG. 2 as "power save mode") to change from default mode to power save mode. Based on receiving that control signal, the control circuitry 230 may control the waveform generator 206 (e.g., using the control signals "ctrl") to reduce the frame rate of the ultrasound imaging being performed by the ultrasound device.

[0092] The frame rate may be dependent on the pulse repetition interval (PRI). PRI may be dependent on various factors (e.g., acoustic travel time and chip offload time, namely the time taken to offload data from the ultrasound-on-chip to another electronic device in the ultrasound device, such as a field-programmable gate array (FPGA)) on top of which may be added transmit waveform deadtime. The control circuitry 230 is configured to control the waveform generators 206, as illustrated generally by the control signal "ctrl" in FIG. 2. The control circuitry 230 may use the control signal "ctrl" to control the waveform generators 206 such that the waveform generators 206 control the pulsers 208 to drive ultrasound transducers 1002 with ultrasound waveforms having particular deadtime (i.e., the amount of time between the end of a pulse and the beginning of the subsequent pulse). Thus, the control circuitry 230 may control the frame rate. In some embodiments, when the ultrasound device changes from default mode to power save mode (e.g., at acts 706, 810, and/or 910), the control circuitry 230 may receive a control signal (labelled in FIG. 2 as "power save mode") to change from default mode to power save mode. Based on receiving that control signal, the control circuitry 230 may control the waveform generator 206 (e.g., using the control signals "ctrl") to reduce the frame rate by increasing the deadtime of transmit waveforms provided to the pulsers 208. Reducing frame rate may reduce power consumed by the ultrasound device.

[0093] Thus, as described above, the control circuitry 230 may control frame rate in power

save mode by controlling deadtime. In some embodiments, the change between the default mode frame rate and the frame rate in power save mode may be different for different presets. In other words, the control circuitry 230 may modify the frame rate parameter value in power save mode differently for different presets. Table 5 lists example default mode frame rates and frame rates in power save mode, for different presets:

Preset	Default Mode Frame Rate (fps)	Power Save Mode Frame Rate (fps)	Percentage Difference
Abdomen	21.9	17.9	18.26484018
Abdomen Deep	31.7	21.6	31.86119874
Aorta & Gallbladder	23.5	17.4	25.95744681
Bladder	25	21	16
Cardiac	27.3	27.3	0
FAST	29	25.4	12.4137931
Lung	20.8	17.2	17.30769231
MSK-Soft Tissue	17.3	14.8	14.45086705
Musculoskeletal	17.3	14.7	15.02890173
Nerve	17.7	14.9	15.81920904
OB 1/GYN	24.3	19.6	19.34156379
OB 2/3	18.6	15.7	15.59139785
Pediatric Abdomen	36.1	30.7	14.95844875
Pediatric Cardiac	40.7	33.8	16.95331695
Pediatric Lung	18.6	15.7	15.59139785
Small Organ	22.7	18.5	18.50220264
Vascular: Access	19.5	16.3	16.41025641
Vascular: Carotid	21.4	17.7	17.28971963
Vascular: Deep Vein	19.5	16.3	16.41025641

Cardiac Deep	33.3	33.3	0

Table 5: Example default mode frame rates and frame rates in power save mode, for different presets.

[0094] While Table 5 lists particular percentage reductions, in some embodiments, the frame rate for certain or all of the presets may be reduced by other percentages in the range of approximately 10% - 35%. In some embodiments, the frame rate for certain or all of the presets may be reduced by a percentage in the range of approximately 10% - 15%. In some embodiments, the frame rate for certain or all of the presets may be reduced by a percentage in the range of approximately 15% - 20%. In some embodiments, the frame rate for certain or all of the presets may be reduced by a percentage in the range of approximately 20% – 25%. In some embodiments, the frame rate for certain or all of the presets may be reduced by a percentage in the range of approximately 25% - 30%. In some embodiments, the frame rate for certain or all of the presets may be reduced by a percentage in the range of approximately 30% - 35%.

[0095] The above description has described example methods for changing from default mode to power save mode: 1. The control circuitry 230 may control the bias generators 228 to reduce bias currents supplied to amplifiers in the receive circuitry 203 2. The control circuitry 230 may control the multiplexing circuitry 1132 to increase the number of ultrasound transducers 1002 coupled to certain TIAs 212, and turn off other TIAs 212 3. The control circuitry 230 may cause instances of receive circuitry 203 to shut off, such that the elevational aperture and/or azimuthal aperture of the ultrasound device is reduced in size 4. The control circuitry may control waveform generators 206 to reduce the frame rate of ultrasound imaging performed by the ultrasound device. It should be appreciated that in some embodiments, the ultrasound device may only use one of these methods. In some embodiments, the ultrasound device may use a subset of these methods. In some embodiments, the ultrasound device may use all these methods. In some embodiments, the ultrasound device may use methods in addition to one or more of these methods.

[0096] Table 6 lists example measurements of changes in power consumption for different presets, when all the parameter value changes listed in Tables 1-5 are implemented:

Preset	Default Mode Power Consumption (W)	Power Save Mode Power Consumption (W)	Difference (%)	Difference (W)
Abdomen	4.04	3.26	19.30693069	0.78
Abdomen Deep	4.56	3.21	29.60526316	1.35
Aorta & Gallbladder	3.84	3	21.875	0.84
Bladder	3.45	2.86	17.10144928	0.59
Cardiac	4.06	3.28	19.21182266	0.78
FAST	3.86	3.14	18.65284974	0.72
Lung	2.98	2.53	15.10067114	0.45
MSK-Soft Tissue	2.95	2.64	10.50847458	0.31
Musculoskeletal	2.94	2.63	10.54421769	0.31
Nerve	3.1	2.81	9.35483871	0.29
OB 1/GYN	4.29	3.29	23.31002331	1
OB 2/3	4.28	3.35	21.72897196	0.93
Pediatric Abdomen	4.1	3.29	19.75609756	0.81
Pediatric Cardiac	3.37	2.73	18.99109792	0.64
Pediatric Lung	3.01	2.73	9.302325581	0.28
Small Organ	3.89	3.18	18.25192802	0.71
Vascular: Access	2.85	2.63	7.719298246	0.22
Vascular: Carotid	3.3	2.89	12.42424242	0.41
Vascular: Deep Vein	3.49	3.08	11.747851	0.41
Cardiac Deep	4.19	3.55	15.27446301	0.64

Table 6: Example measurements of changes in power consumption for different presets, when all the parameter value changes listed in Tables 1-5 are implemented:

[0097] While Table 6 lists particular percentage reductions, in some embodiments, the power consumption for certain or all of the presets may be reduced by other percentages in the range of approximately 5% - 35%. In some embodiments, the power consumption for certain or all

of the presets may be reduced by a percentage in the range of approximately 5% - 10%. In some embodiments, the power consumption for certain or all of the presets may be reduced by a percentage in the range of approximately 10% - 15%. In some embodiments, the power consumption for certain or all of the presets may be reduced by a percentage in the range of approximately 15% - 20%. In some embodiments, the power consumption for certain or all of the presets may be reduced by a percentage in the range of approximately 20% - 25%. In some embodiments, the power consumption for certain or all of the presets may be reduced by a percentage in the range of approximately 25% - 30%. In some embodiments, the power consumption for certain or all of the presets may be reduced by a percentage in the range of approximately 30% - 35%.

[0098] While Table 6 lists particular reductions, in some embodiments, the power consumption for certain or all of the presets may be reduced by other amounts in the range of approximately 0.15 W – 1.35 W. In some embodiments, the power consumption for certain or all of the presets may be reduced by an amount in the range of approximately 0.15 W – 0.3 W. In some embodiments, the power consumption for certain or all of the presets may be reduced by an amount in the range of approximately 0.3 W – 0.5 W. In some embodiments, the power consumption for certain or all of the presets may be reduced by an amount in the range of approximately 0.5 W – 0.75 W. In some embodiments, the power consumption for certain or all of the presets may be reduced by an amount in the range of approximately 0.75 W – 1 W. In some embodiments, the power consumption for certain or all of the presets may be reduced by an amount in the range of approximately 1 W – 1.25 W. In some embodiments, the power consumption for certain or all of the presets may be reduced by an amount in the range of approximately 1.25 W – 1.35 W.

[0099] In Table 6, the average percentage decrease in power consumption among all the presets is approximately 16.5%. In some embodiments, the average percentage decrease in power consumption among all the presets may be another percentage in the range of approximately 5%- 30%. In some embodiments, the average percentage decrease in power consumption among all the presets may be a percentage in the range of approximately 5%- 10%. In some embodiments, the average percentage decrease in power consumption among all the presets may be a percentage in the range of approximately 10%- 15%. In some embodiments, the average percentage decrease in power consumption among all the presets may be a percentage in the range of approximately 15%- 20%. In some embodiments, the average percentage decrease in power consumption among all the presets may be a

percentage in the range of approximately 20%- 25%. In some embodiments, the average percentage decrease in power consumption among all the presets may be a percentage in the range of approximately 25%- 30%.

[00100] In Table 6, the maximum decrease in power consumption achieved is 1.35 W, for the abdomen deep preset. In some embodiments, the maximum decrease in power consumption achieved for a particular preset may be a different amount in the range of approximately 0.75 W – 1.35 W. In some embodiments, the maximum decrease in power consumption achieved for a particular preset may be a different amount in the range of 0.75 W – 1 W. In some embodiments, the maximum decrease in power consumption achieved for a particular preset may be a different amount in the range of 1 W – 1.25 W. In some embodiments, the maximum decrease in power consumption achieved for a particular preset may be a different amount in the range of 1.25 W – 1.35 W.

[00101] In some embodiments, the processing device may control the ultrasound device to reduce power consumption using adaptive imaging optimization. The adaptive imaging optimization may be based on the processing device detecting motion in the ultrasound images currently being collected by the ultrasound device and/or detecting motion of the ultrasound device.

[00102] Non-limiting examples of methods for detecting motion in ultrasound images (e.g., heartbeats) may be found in the following articles, the contents of which are incorporated by reference herein in their entireties:

[00103] Kim S, Aglyamov SR, Park S, O'Donnell M, Emelianov SY. An autocorrelation-based method for improvement of sub-pixel displacement estimation in ultrasound strain imaging. IEEE Trans Ultrason Ferroelectr Freq Control. 2011 Apr;58(4):838-43.

[00104] Dai X, Lei Y, Roper J, Chen Y, Bradley JD, Curran WJ, Liu T, Yang X. Deep learning-based motion tracking using ultrasound images. Med Phys. 2021 Dec;48(12):7747-7756.

[00105] Yeung F, Levinson SF, Fu D, Parker KJ. Feature-adaptive motion tracking of ultrasound image sequences using a deformable mesh. IEEE Trans Med Imaging. 1998 Dec;17(6):945-56.

[00106] The processing device may determine whether motion in the ultrasound images exceeds a threshold ("high") or does not exceed a threshold ("low").

[00107] To detect motion of the ultrasound device, the ultrasound device may include

an inertial measurement unit (IMU, e.g., IMU 123). The IMU may communicate motion and/or orientation data to the processing device over a wired or wireless connection, and the processing device may use this data to determine motion of the ultrasound device. For example, a 9-axis IMU may include an accelerometer to measure 3 axes of linear acceleration, a gyroscope to measure 3 axes of angular velocity, and a magnetometer to measure 3 axes of orientation relative to gravity. The processing device may determine linear velocity of the ultrasound device by integrating linear acceleration data from the accelerometer, and/or the processing device may determine angular velocity using data directly from the gyroscope. As another example, a 6-axis IMU may include an accelerometer to measure 3 axes of linear acceleration and a gyroscope to measure 3 axes of angular acceleration. The processing device may determine linear velocity of the ultrasound device by integrating linear acceleration data from the accelerometer, and/or the processing device may determine angular velocity by integrating angular acceleration data from the gyroscope. Having obtained linear velocity and/or angular velocity data, the processing device may determine if the linear velocity exceeds a threshold or the angular velocity exceeds a threshold ("high"), or if neither the linear velocity nor the angular velocity exceeds a threshold ("low"). In some embodiments, the processing device may only analyze linear velocity. In some embodiments, the processing device may only analyze angular velocity.

[00108] The processing device may then control the ultrasound device to reduce power by modifying parameters as shown in Table 7. The ultrasound device may reduce frame rate and/or reduce aperture size (e.g., azimuthal and/or elevational aperture size) using any of the methods described above.

		Device Motion	
		Low	High
Image Motion	Low	Reduce Frame rate	Reduce aperture size
	High	Do not reduce frame rate or aperture size	Reduce aperture size

Table 7. Parameters modified to reduce power consumption based on image motion and transducer motion.

[00109] When ultrasound device motion is high, it may be important to keep frame rate to better capture the motion, and less important to generate the highest quality image in each frame. Thus, reducing aperture size rather than frame rate may be helpful in reducing power consumption and also result in acceptable image quality. When ultrasound image motion is low, it may be possible to reduce frame rate without needing to reduce aperture size, and still maintain acceptable image quality. When ultrasound device motion is low and ultrasound image motion is high, acceptable image quality may be maintained by not reducing either frame rate or aperture size is reduced. In some embodiments, the processing device may automatically control the ultrasound device to reduce frame rate or aperture size, in accordance with Table 7, based on detecting ultrasound device motion level and/or ultrasound image motion level, without user input to reduce power consumption. In some embodiments, the processing device may control the ultrasound device to reduce frame rate or aperture size, in accordance with Table 7, based on a user input to reduce power consumption. In some embodiments, the processing device may automatically control the ultrasound device to reduce frame rate or aperture size, in accordance with Table 7, based on the ultrasound device's battery charging level and/or temperature, without user input to reduce power consumption. In some embodiments, the processing device may control the ultrasound device to reduce frame rate or aperture size, in accordance with Table 7, based on the ultrasound device's battery charging level and/or temperature and also based on a user's response to a prompt to power consumption.

[00110] The indefinite articles "a" and "an," as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean "at least one."

[00111] The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified.

[00112] As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one

element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified.

[00113] Use of ordinal terms such as "first," "second," "third," etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

[00114] As used herein, reference to a numerical value being between two endpoints should be understood to encompass the situation in which the numerical value can assume either of the endpoints. For example, stating that a characteristic has a value between A and B, or between approximately A and B, should be understood to mean that the indicated range is inclusive of the endpoints A and B unless otherwise noted.

[00115] The terms "approximately" and "about" may be used to mean within ±20% of a target value in some embodiments, within ±10% of a target value in some embodiments, within ±5% of a target value in some embodiments, and yet within ±2% of a target value in some embodiments. The terms "approximately" and "about" may include the target value.

[00116] Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having," "containing," "involving," and variations thereof herein, is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

[00117] Having described above several aspects of at least one embodiment, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be object of this disclosure. Accordingly, the foregoing description and drawings are by way of example only.

CLAIMS

What is claimed:

1. An ultrasound device, comprising:

ultrasound transducers;

an ultrasound transducer array comprising the ultrasound transducers and having an azimuthal dimension and an elevational dimension;

ultrasound circuitry comprising:

receive circuitry comprising:

one or more amplifiers and an analog-to-digital converter (ADC), wherein the one or more amplifiers comprises transimpedance amplifiers (TIAs); and

multiplexing circuitry configured to couple a number of the ultrasound transducers to each of certain of the TIAs;

one of more bias generators configured to supply bias currents to the one or more amplifiers of the receive circuitry;

transmit circuitry comprising:

a pulser configured to drive the ultrasound transducers to emit ultrasound signals; and

a waveform generator configured to control the pulser to emit the ultrasound signals such that the emitted ultrasound signals have particular waveforms; and

control circuitry configured to:

receive a control signal to change from a default mode to a power save mode; and

based on receiving the control signal, cause the ultrasound device to change from the default mode to the power save mode, wherein causing the ultrasound device to change from the default mode to the power save mode comprises modifying, by the control circuitry, one or more parameter values of the ultrasound circuitry from default mode parameter values to power save mode parameter values, and wherein modifying the one or more parameter values of the ultrasound circuitry comprises at least one of:

controlling, by the control circuitry, the one or more bias generators to reduce one or more of the bias currents supplied to one or more of the

amplifiers in the receive circuitry;

controlling, by the control circuitry:

the multiplexing circuitry to increase the number of the ultrasound transducers coupled to each of certain of the TIAs; and

certain other of the TIAs to turn off;

controlling, by the control circuitry, the one or more amplifiers and the ADC of the receive circuitry to turn off; and

controlling, by the control circuitry, the waveform generator to decrease a frame rate of ultrasound imaging performed by the ultrasound device.

2. The ultrasound device of claim 1, wherein the one or more bias generators are configured to supply at least three levels of bias currents to the one or more amplifiers of the receive circuitry.

3. The ultrasound device of claim 1, wherein the one or more bias generators are configured, when reducing the one or more of the bias currents supplied to the one or more of the amplifiers in the receive circuitry, to reduce the one or more of the bias currents by a percentage in a range of approximately 20% - 60%.

4. The ultrasound device of claim 1, wherein the one or more bias generators are configured, when reducing the one or more of the bias currents supplied to the one or more of the amplifiers in the receive circuitry, to reduce the one or more of the bias currents by a percentage in a range of approximately 2.5% - 40%.

5. The ultrasound device of claim 1, wherein the control circuitry is configured, when controlling the multiplexing circuitry to increase the number of the ultrasound transducers coupled to each of certain of the TIAs, to control the multiplexing circuitry to increase the number of the ultrasound transducers coupled to each of certain of the TIAs by two times.

6. The ultrasound device of claim 1, wherein the ultrasound transducers coupled to each of certain of the TIAs are in a column along the elevational dimension of the ultrasound transducer array and located at a particular position along the azimuthal dimension of the ultrasound transducer array.

7. The ultrasound device of claim 1, wherein the control circuitry is configured, when controlling the one or more amplifiers and the ADC of the receive circuitry to turn off, to control multiple instances of the receive circuitry to turn off such that a size of an aperture of the ultrasound transducer array along the elevational dimension of the ultrasound transducer array is reduced by a percentage in a range of approximately 25% – 50%.

8. The ultrasound device of claim 1, wherein the control circuitry is configured, when controlling the one or more amplifiers and the ADC of the receive circuitry to turn off, to control multiple instances of the receive circuitry to turn off such that a size of an aperture of the ultrasound transducer array along the azimuthal dimension of the ultrasound transducer array is reduced by a percentage in a range of approximately 15% – 40%.

9. The ultrasound device of claim 1, wherein the control circuitry is configured, when controlling the waveform generator to decrease the frame rate of the ultrasound imaging performed by the ultrasound device, to control the waveform generator to decrease the frame rate of the ultrasound imaging performed by the ultrasound device by a percentage in a range of approximately 10% - 35%.

10. The ultrasound device of claim 1, wherein the control circuitry is configured, when controlling the waveform generator to decrease the frame rate of the ultrasound imaging performed by the ultrasound device, to control the waveform generator to increase an amount of deadtime in the waveforms of the emitted ultrasound signals.

11. The ultrasound device of claim 1, wherein an average percentage decrease in power consumption among all presets of the ultrasound device in the power save mode is in a range of approximately 5%- 30%.

12. The ultrasound device of claim 1, wherein a maximum decrease in power consumption for a particular preset of the ultrasound device in the power save mode is in a range of approximately 0.75 W – 1.35 W.

13. An ultrasound device, comprising:

ultrasound transducers;

an ultrasound transducer array comprising the ultrasound transducers and having an azimuthal dimension and an elevational dimension; and

ultrasound circuitry comprising receive circuitry, transmit circuitry, and control circuitry, wherein the control circuitry is configured to:

determine a first anatomical region type of a subject that is being analyzed using the ultrasound transducer array;

receive a first control signal to change from a default mode to a first power save mode among a plurality of power save modes, wherein the first power save mode is associated with the first anatomical region; and

based on receiving the first control signal, cause the ultrasound device to change from the default mode to the first power save mode associated with the first anatomical region; and

wherein a respective power save mode among the plurality of power save modes is different for different anatomical region types.

14. The ultrasound device of claim 13, wherein the ultrasound circuitry comprises one of more bias generators configured to supply bias currents to one or more amplifiers of the receive circuitry, and wherein the first power save mode corresponds to reducing one or more of the bias currents supplied to the one or more of the amplifiers.

15. The ultrasound device of claim 13, wherein the receive circuitry comprises multiplexing circuitry configured to couple a predetermined number of ultrasound transducers to one or more amplifiers, and wherein the first power save mode corresponds to increasing the predetermined number of the ultrasound transducers coupled to the one or more amplifiers.

16. The ultrasound device of claim 13, wherein the receive circuitry comprises transimpedance amplifiers (TIAs), and wherein the first power save mode corresponds to at least one of the TIAs turning off.

17. The ultrasound device of claim 13, wherein the receive circuitry comprises one or more amplifiers and an analog-to-digital converter (ADC), and wherein the first power save

mode corresponds to at least one of the one or more amplifiers and the ADC turning off.

18. The ultrasound device of claim 13, wherein the transmit circuitry further comprises:

a pulser configured to drive the ultrasound transducers to emit ultrasound signals; and

a waveform generator configured to control the pulser to emit the ultrasound signals such that the emitted ultrasound signals have one or more predetermined waveforms, and

wherein the first power save mode corresponds to decreasing a frame rate of the waveform generator.

19. The ultrasound device of claim 18, wherein decreasing the frame rate comprises increasing an amount of deadtime in the one or more predetermined waveforms of the emitted ultrasound signals.

20. The ultrasound device of claim 13, wherein the first power save mode corresponds to reducing a size of an aperture of the ultrasound transducer array along the elevational dimension and/or the azimuthal dimension.

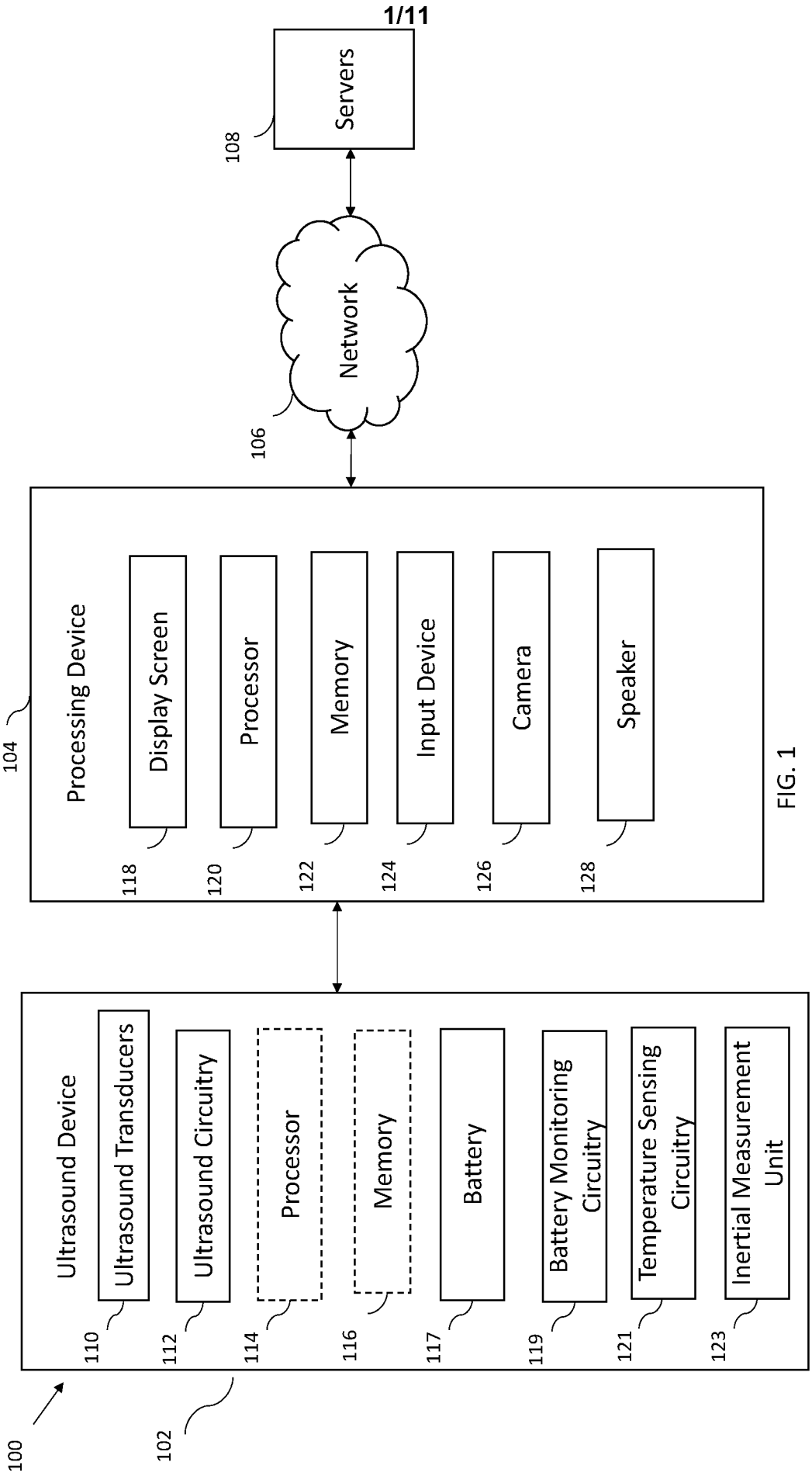
Servers
108
Network
106
Processing Device
104
Display Screen
118
Processor
120
Memory
122
Input Device
124
Camera
126
Speaker
128
Ultrasound Device
Ultrasound Transducers
110
Ultrasound Circuitry
112
Processor
114
Memory
116
Battery
117
Battery Monitoring Circuitry
119
Temperature Sensing Circuitry
121
Inertial Measurement Unit
123
100
102

FIG. 1

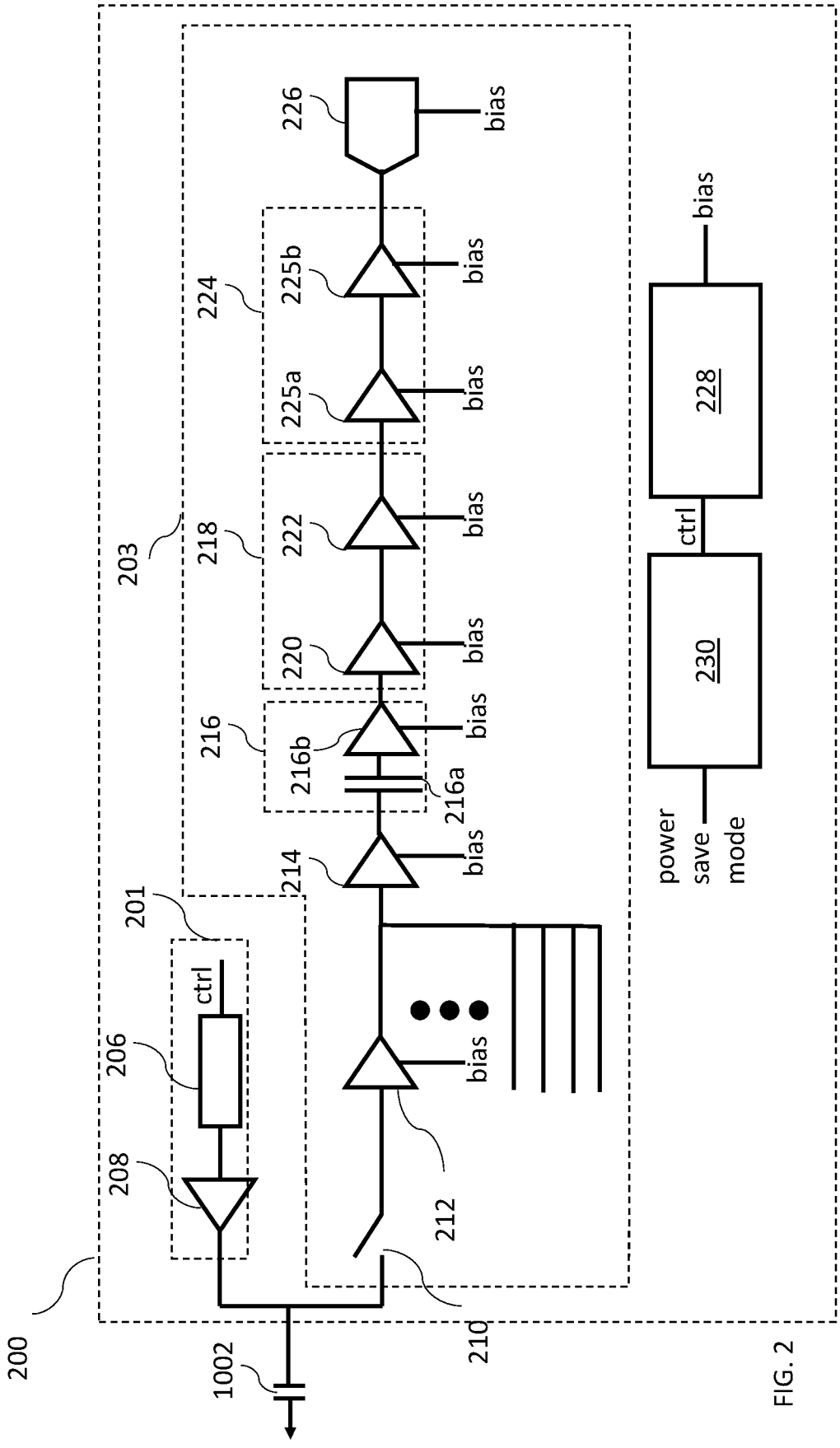
200
1002
210
212
208
206
ctrl
201
214
bias
216a
216b
216
220
222
218
203
224
225a
225b
226
bias
228
ctrl
230
power save mode

FIG. 2

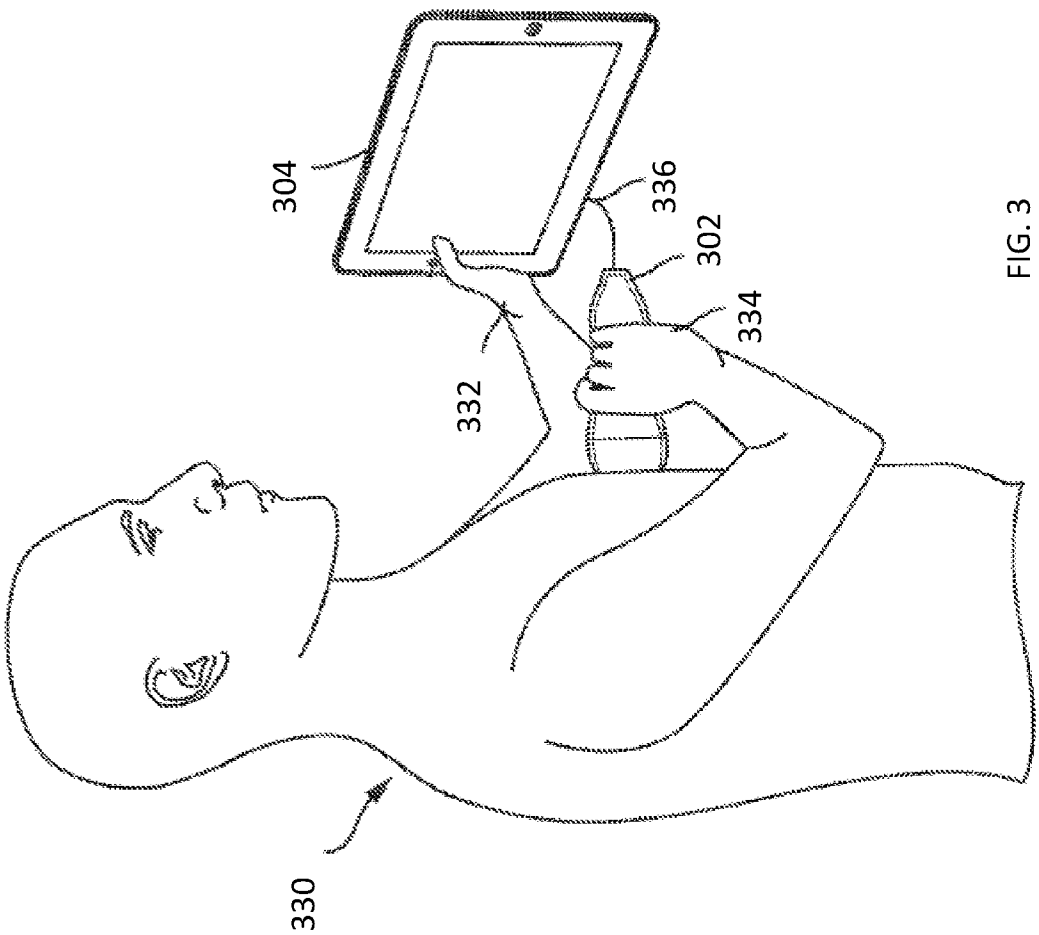

FIG. 3

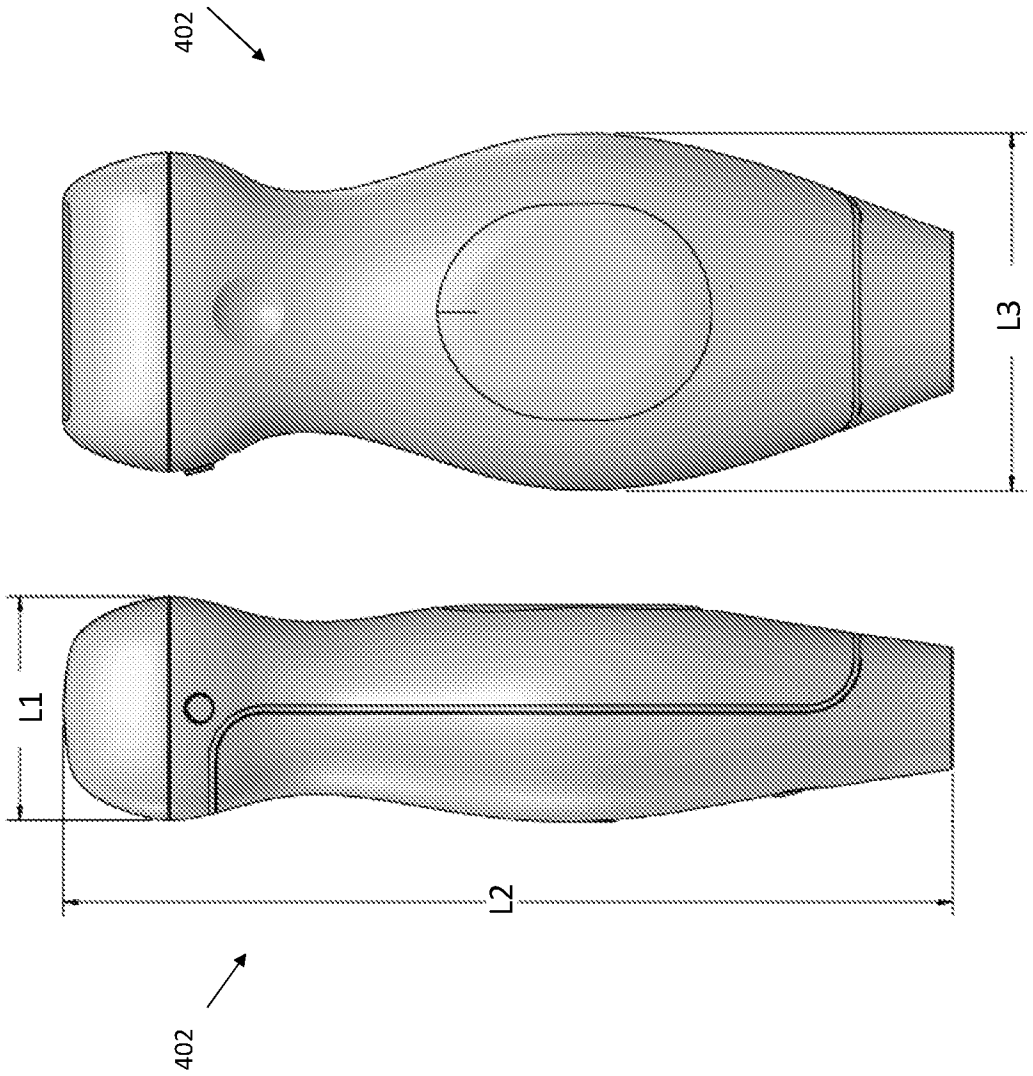

FIG. 4B

FIG. 4A

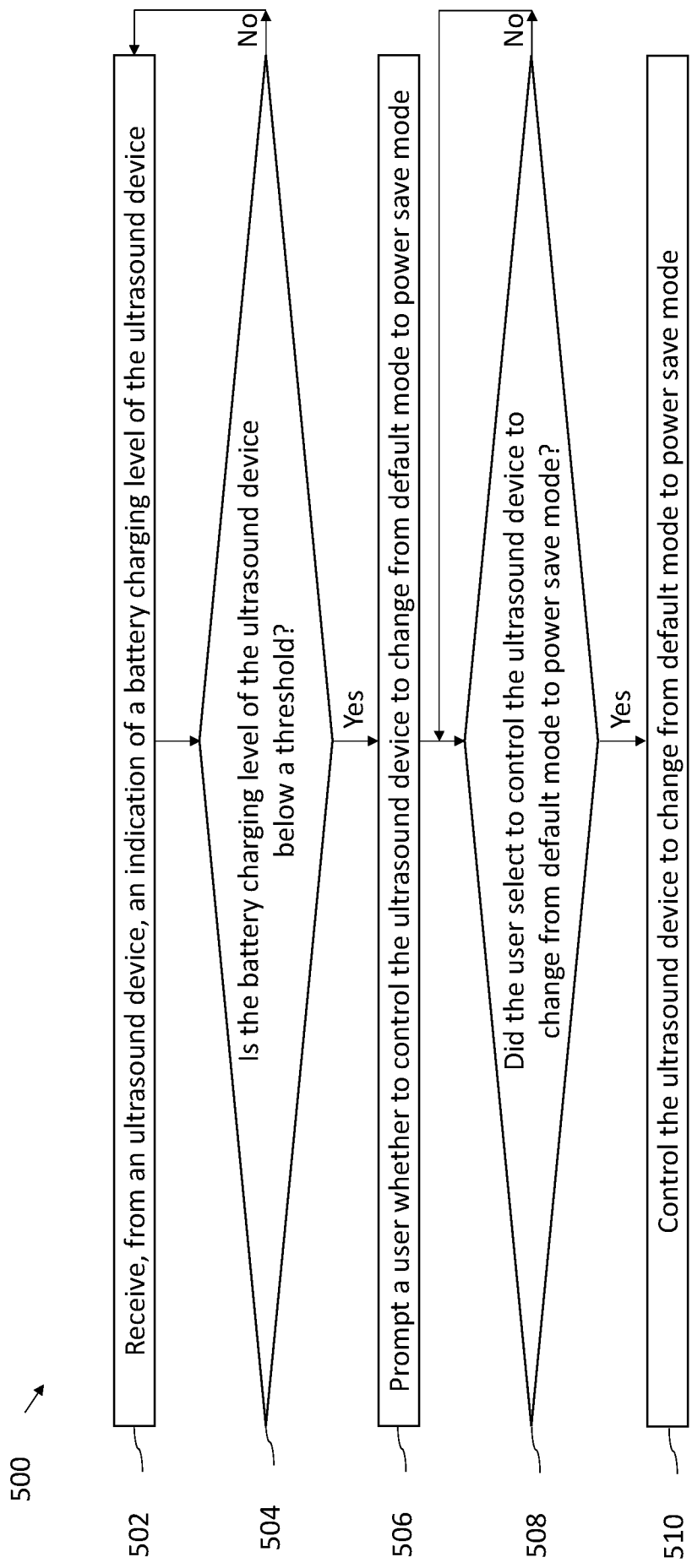
500
Receive, from an ultrasound device, an indication of a battery charging level of the ultrasound device
502
Is the battery charging level of the ultrasound device below a threshold?
504
No
Yes
Prompt a user whether to control the ultrasound device to change from default mode to power save mode
506
Did the user select to control the ultrasound device to change from default mode to power save mode?
508
No
Yes
Control the ultrasound device to change from default mode to power save mode
510

FIG. 5

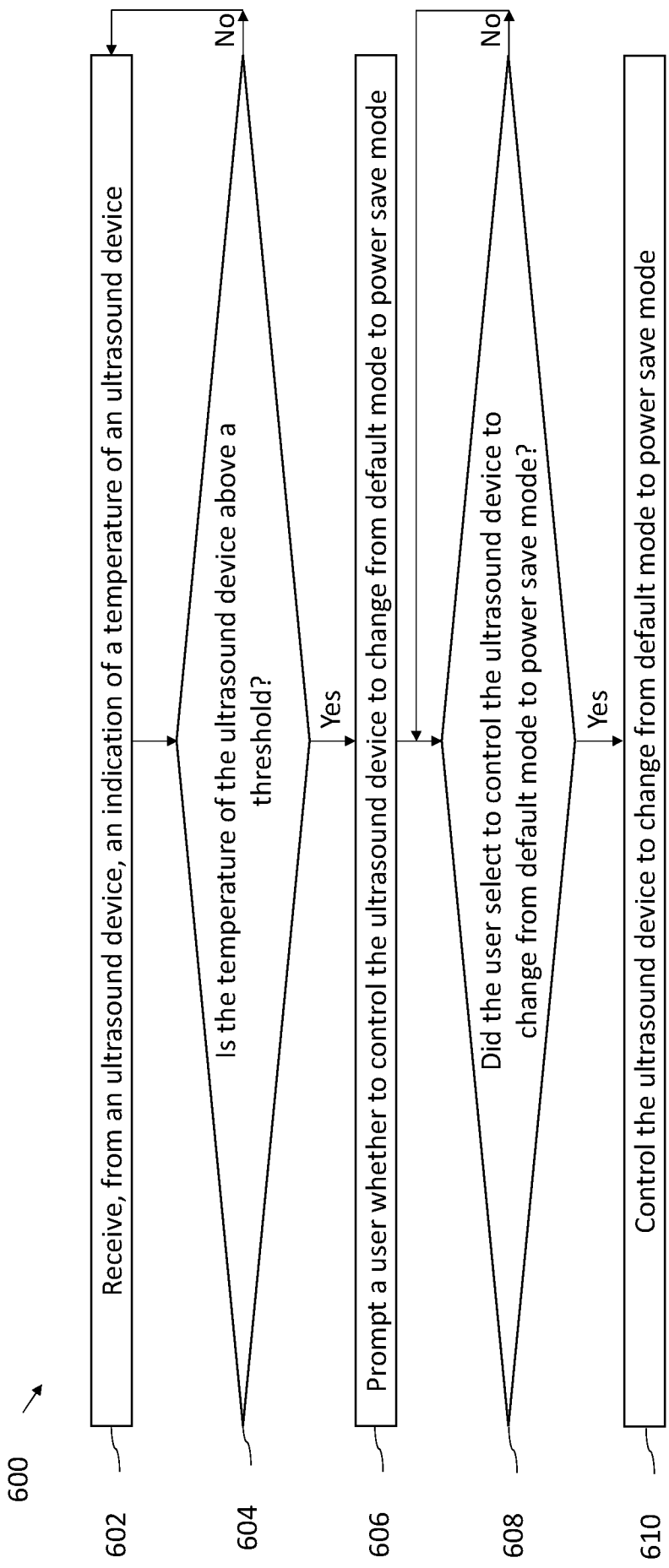
600
Receive, from an ultrasound device, an indication of a temperature of an ultrasound device
602
Is the temperature of the ultrasound device above a threshold?
604
No
Yes
Prompt a user whether to control the ultrasound device to change from default mode to power save mode
606
Did the user select to control the ultrasound device to change from default mode to power save mode?
608
No
Yes
Control the ultrasound device to change from default mode to power save mode
610

FIG. 6

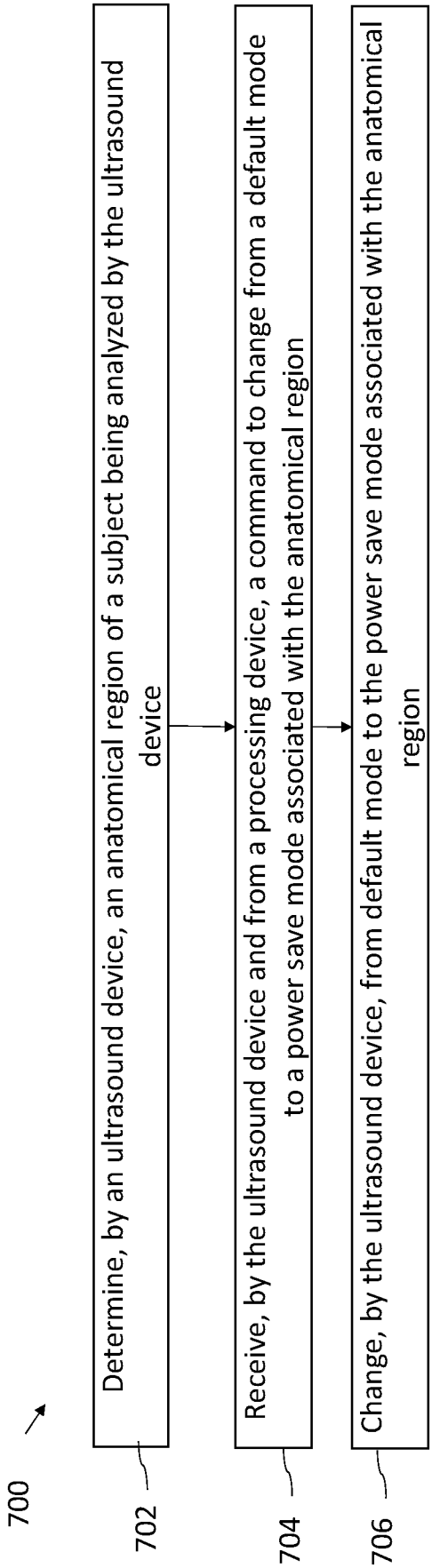
700
Determine, by an ultrasound device, an anatomical region of a subject being analyzed by the ultrasound device
702
Receive, by the ultrasound device and from a processing device, a command to change from a default mode to a power save mode associated with the anatomical region
704
Change, by the ultrasound device, from default mode to the power save mode associated with the anatomical region
706

FIG. 7

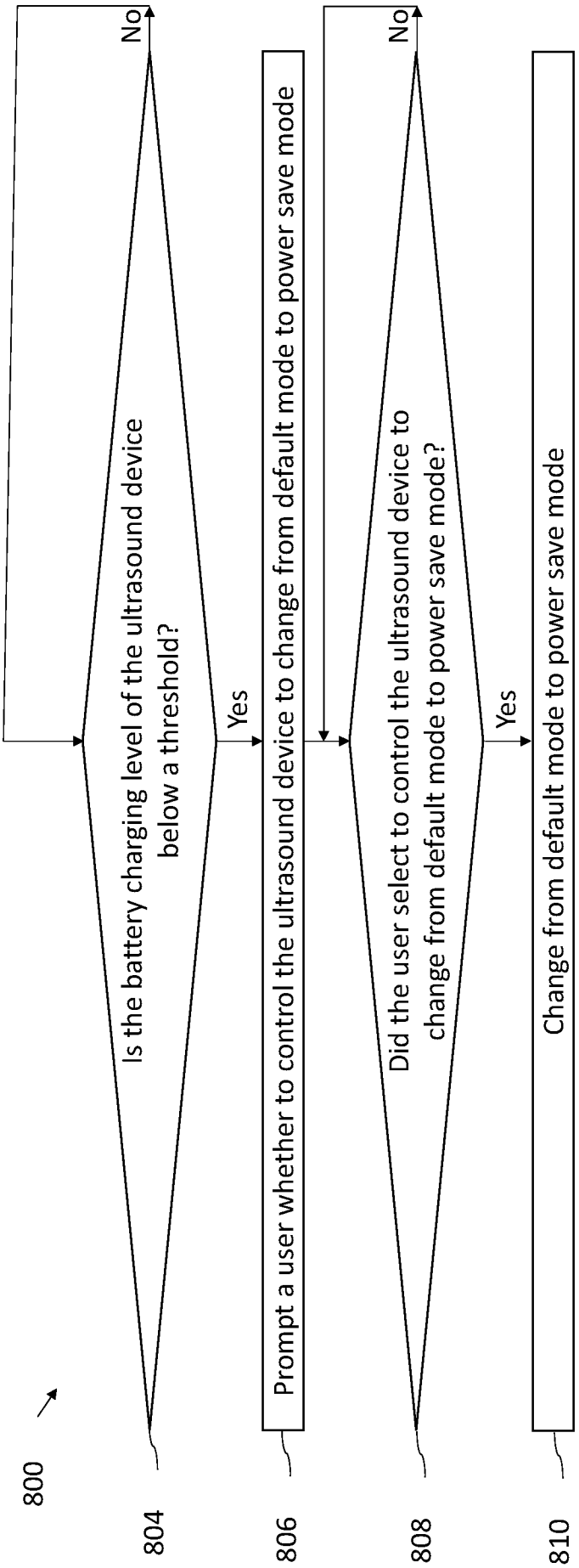
800
Is the battery charging level of the ultrasound device below a threshold?
No
Yes
804
Prompt a user whether to control the ultrasound device to change from default mode to power save mode
806
Did the user select to control the ultrasound device to change from default mode to power save mode?
No
Yes
808
Change from default mode to power save mode
810

FIG. 8

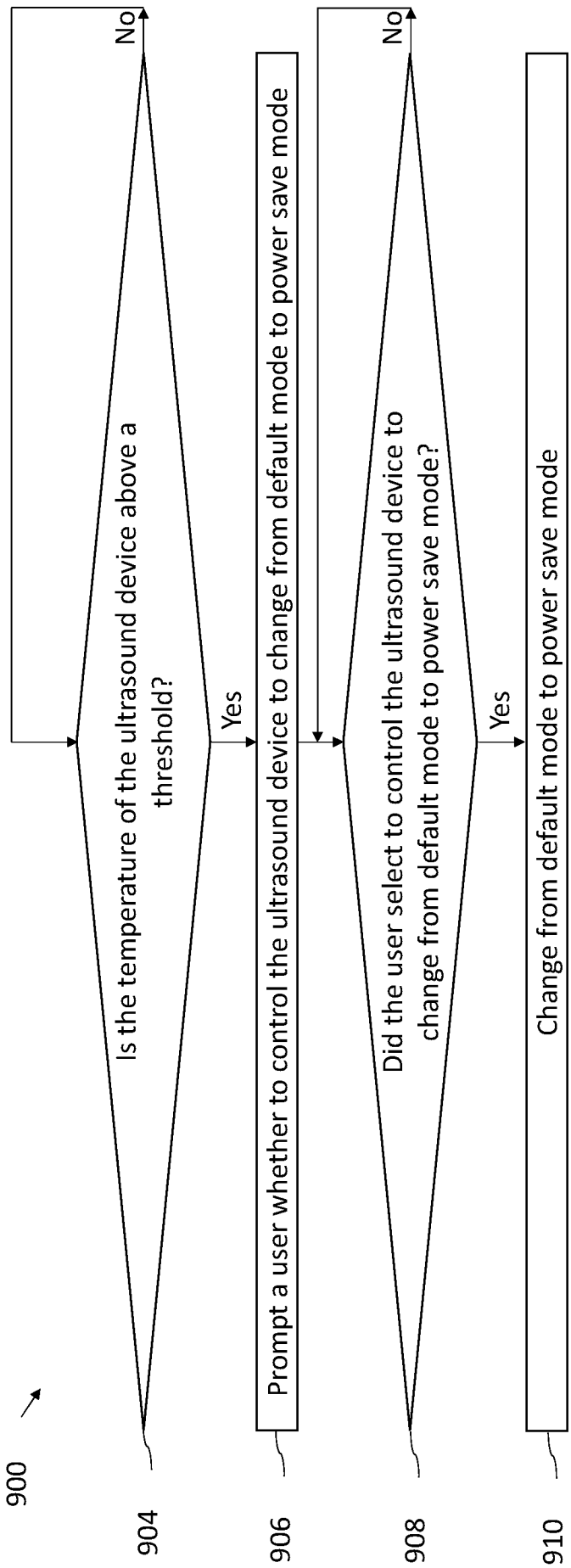
900
Is the temperature of the ultrasound device above a threshold?
No
Yes
904
Prompt a user whether to control the ultrasound device to change from default mode to power save mode
906
Did the user select to control the ultrasound device to change from default mode to power save mode?
No
Yes
908
Change from default mode to power save mode
910

FIG. 9

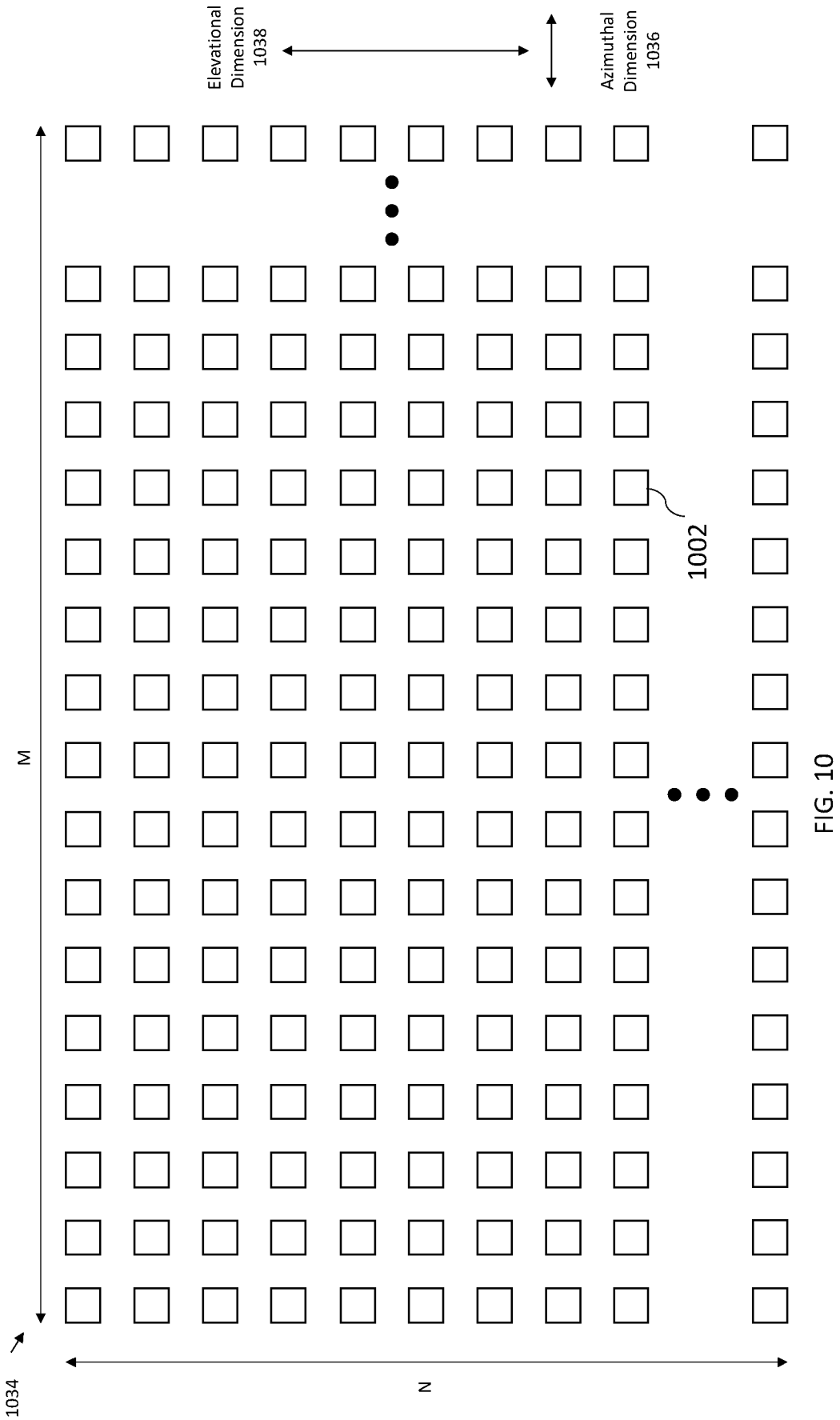
Elevational Dimension 1038
Azimuthal Dimension 1036
1002
M
N
1034

FIG. 10

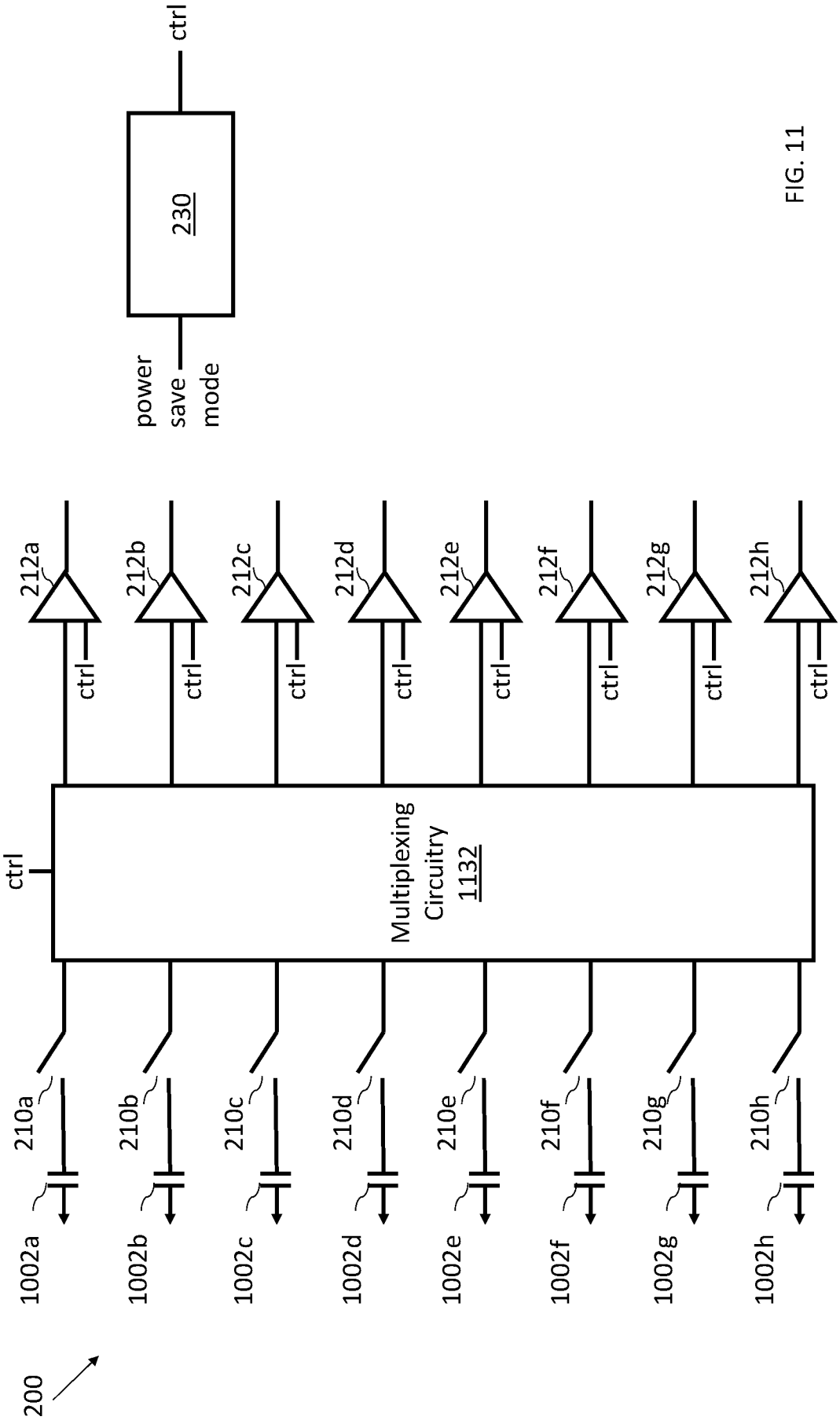
200
1002a
1002b
1002c
1002d
1002e
1002f
1002g
1002h
210a
210b
210c
210d
210e
210f
210g
210h
ctrl
Multiplexing Circuitry 1132
212a
212b
212c
212d
212e
212f
212g
212h
ctrl
power save mode
230
ctrl

FIG. 11