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(54) **FLEXIBLE ULTRASOUND SYSTEM FOR BOTH IMAGING AND HIGH POWER DELIVERY APPLICATIONS**

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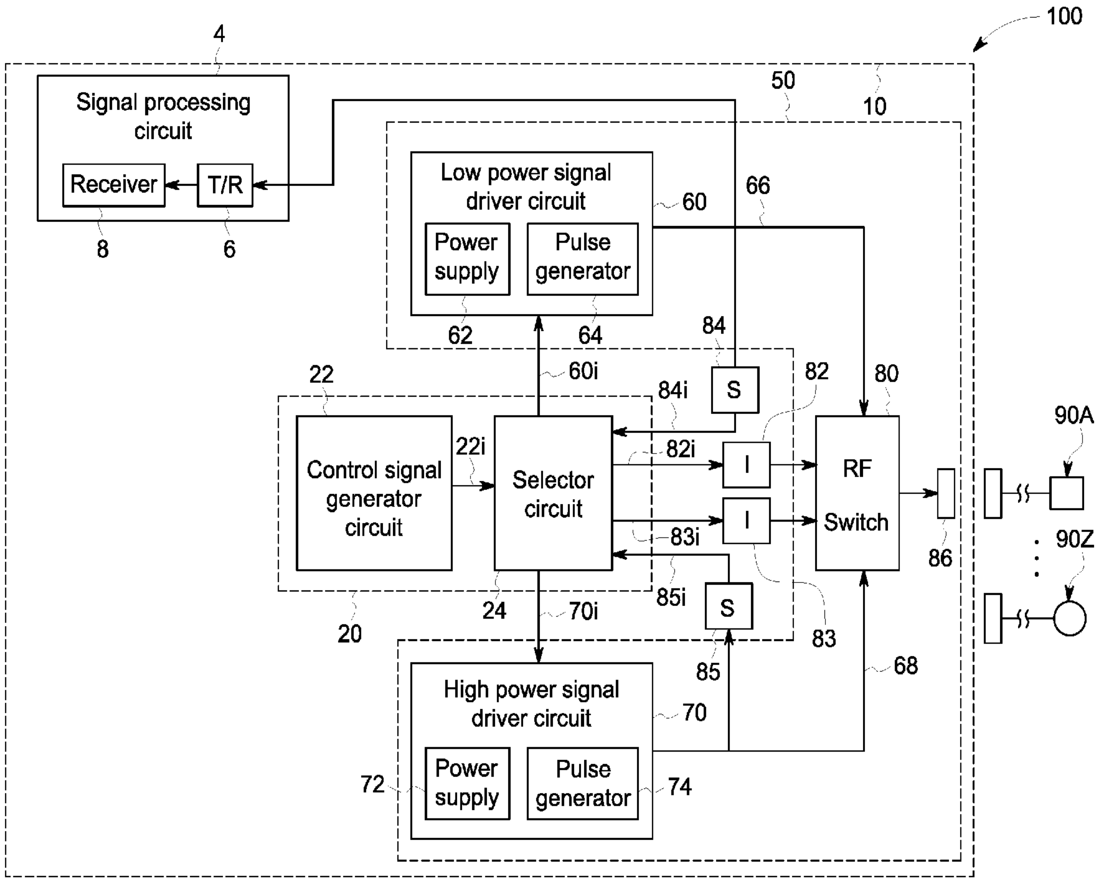
(57) **ABSTRACT**

There is set forth herein an ultrasound signal generating circuit having a control circuit which can include a control circuit having a control signal generating circuit; a low power signal driver circuit for providing a low power ultrasound signal; a high power signal driver circuit for providing a high power ultrasound signal; and a radiofrequency switch configured to transmit the low power ultrasound signal and the high power ultrasound signal to the ultrasound probe, wherein the radiofrequency switch isolates the low power signal driver circuit from the high power signal driver circuit; wherein the ultrasound signal generating circuit is configured so that the radiofrequency switch transmits an output low power ultrasound signal output by the low power signal driver circuit or an output high power ultrasound signal output by the high power signal driver circuit based on an output of the control signal generating circuit.



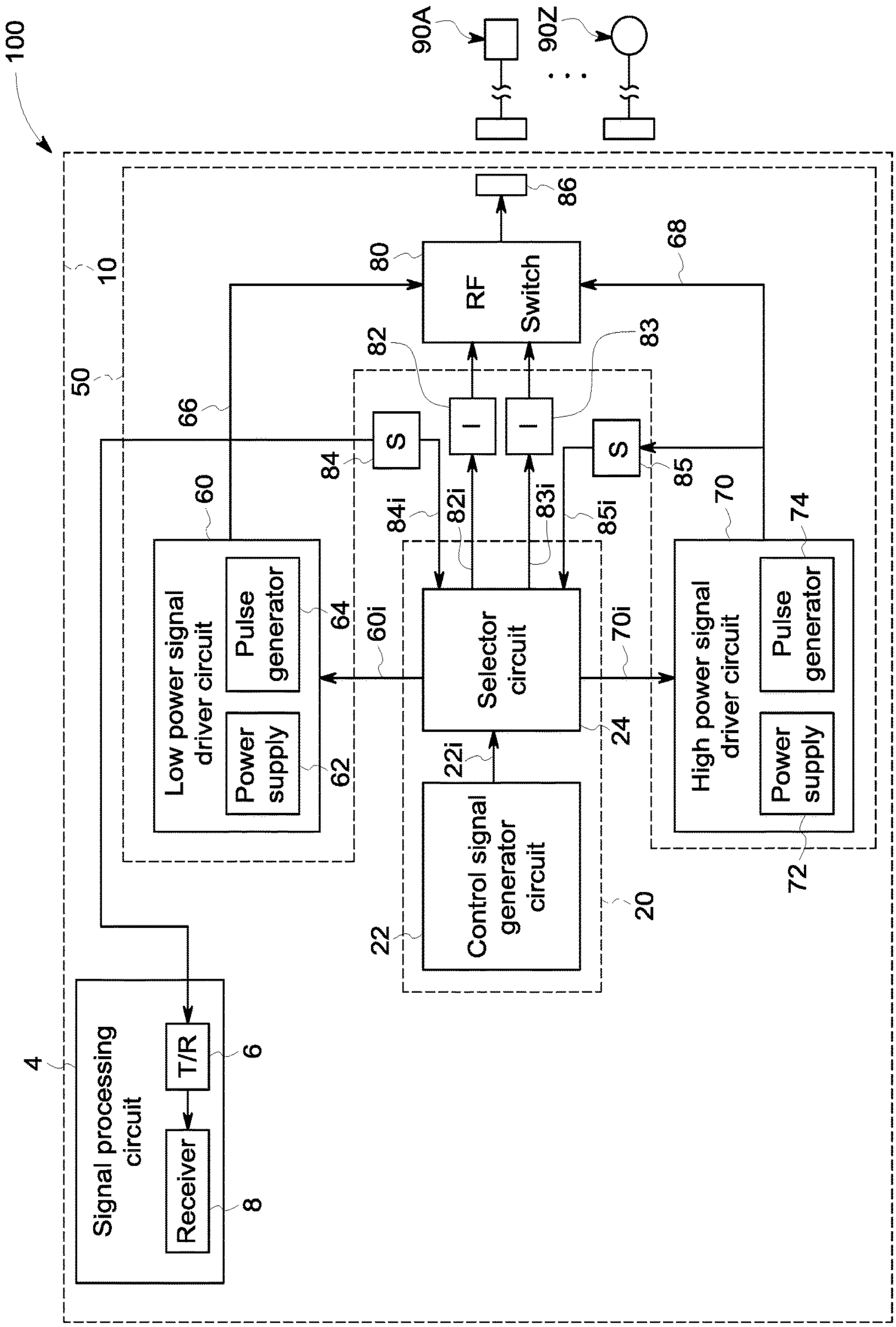

100
90A
90Z
10
50
86
80
RF
Switch
68
66
82
83
S
I
I
S
84
85
60
70
84i
82i
83i
85i
74
Low power signal
driver circuit
Pulse
generator
Power
supply
64
62
60i
Selector
circuit
70i
24
22i
High power signal
driver circuit
Pulse
generator
Power
supply
72
Control signal
generator
circuit
22
20
4
Signal processing
circuit
T/R
6
Receiver
8

FIG. 1

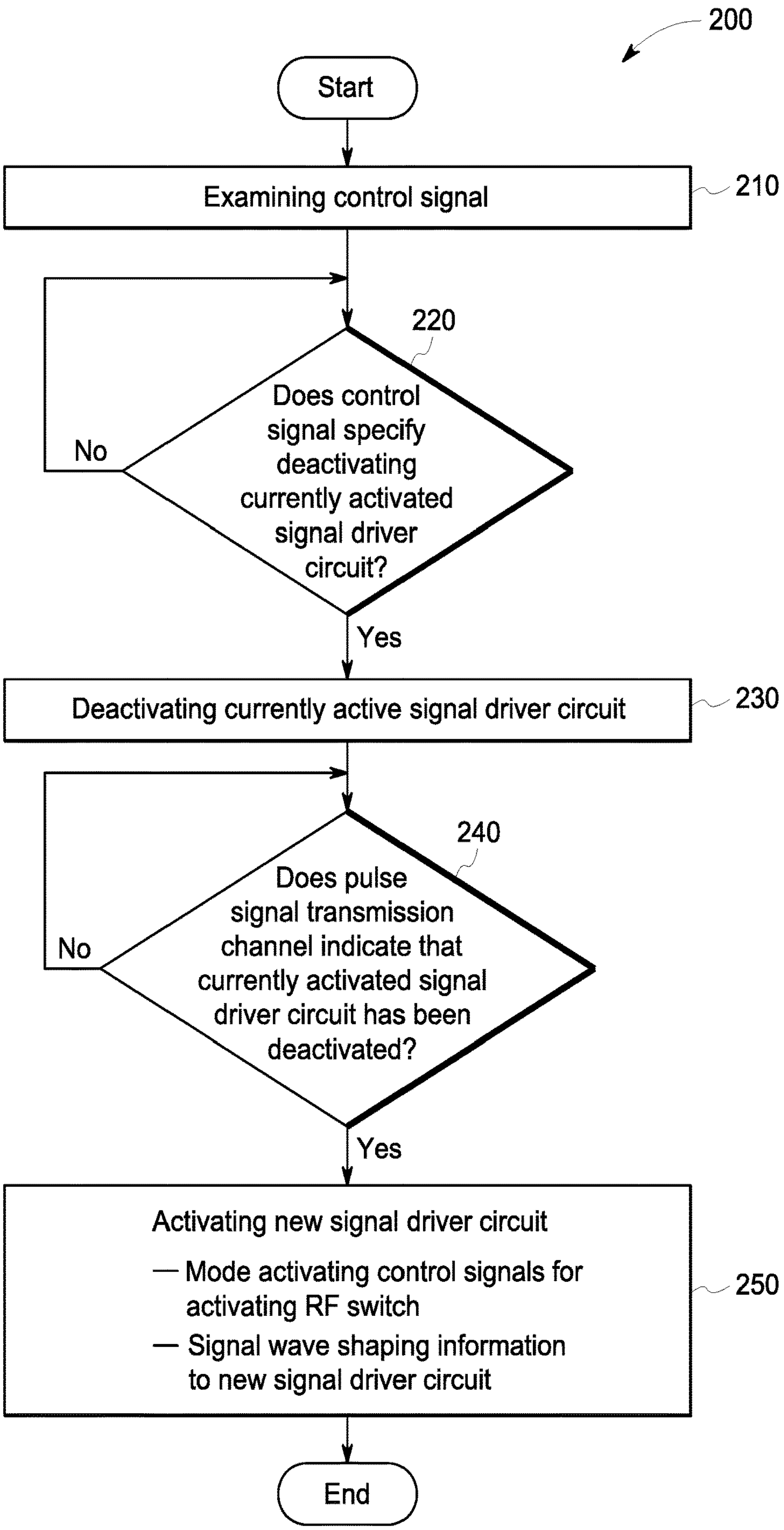

200
Start
Examining control signal
210
220
Does control signal specify deactivating currently activated signal driver circuit?
No
Yes
Deactivating currently active signal driver circuit
230
240
Does pulse signal transmission channel indicate that currently activated signal driver circuit has been deactivated?
No
Yes
Activating new signal driver circuit
— Mode activating control signals for activating RF switch
— Signal wave shaping information to new signal driver circuit
250
End

FIG. 2

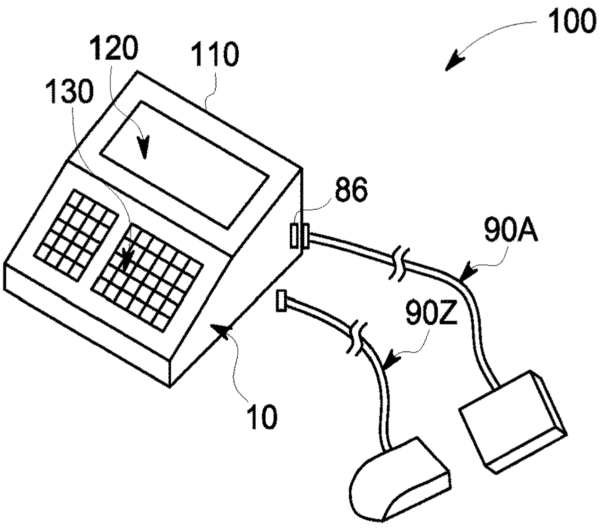

100
120
110
130
86
90A
90Z
10

FIG. 3

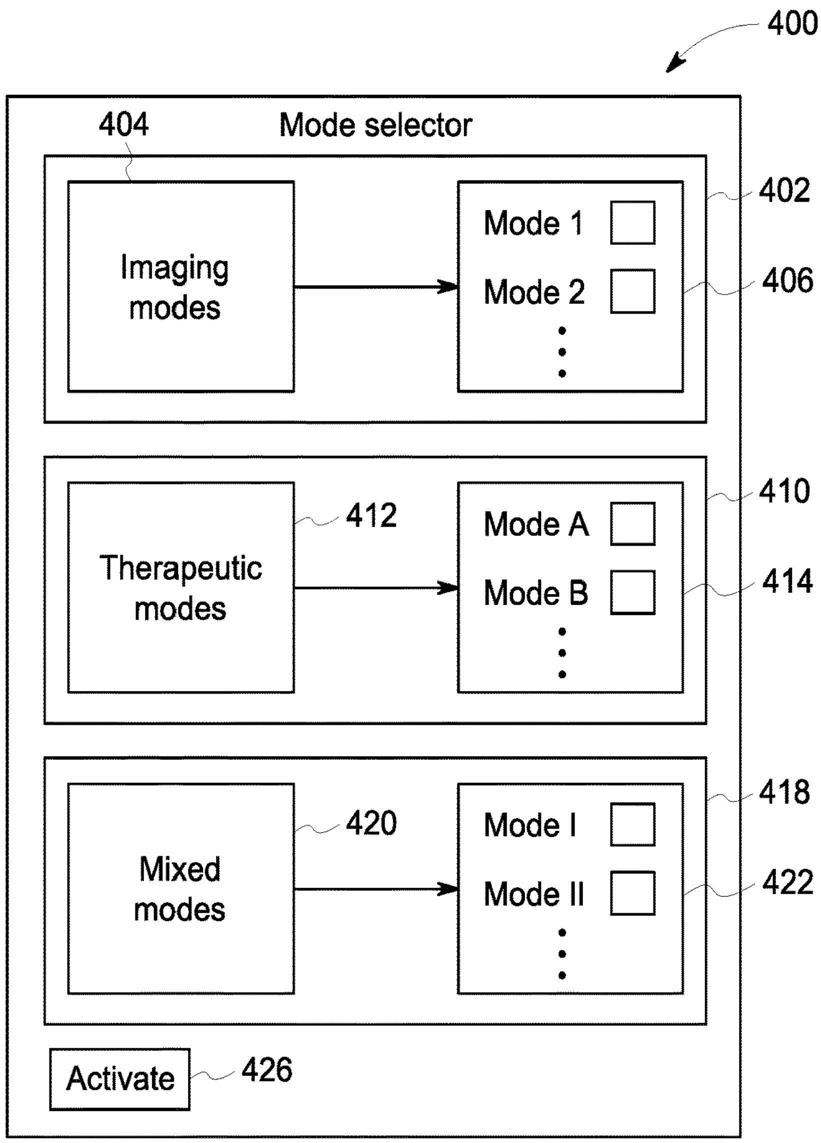

400
Mode selector
404
402
Imaging modes
Mode 1
Mode 2
406
410
412
Therapeutic modes
Mode A
Mode B
414
418
420
Mixed modes
Mode I
Mode II
422
Activate
426

FIG. 4

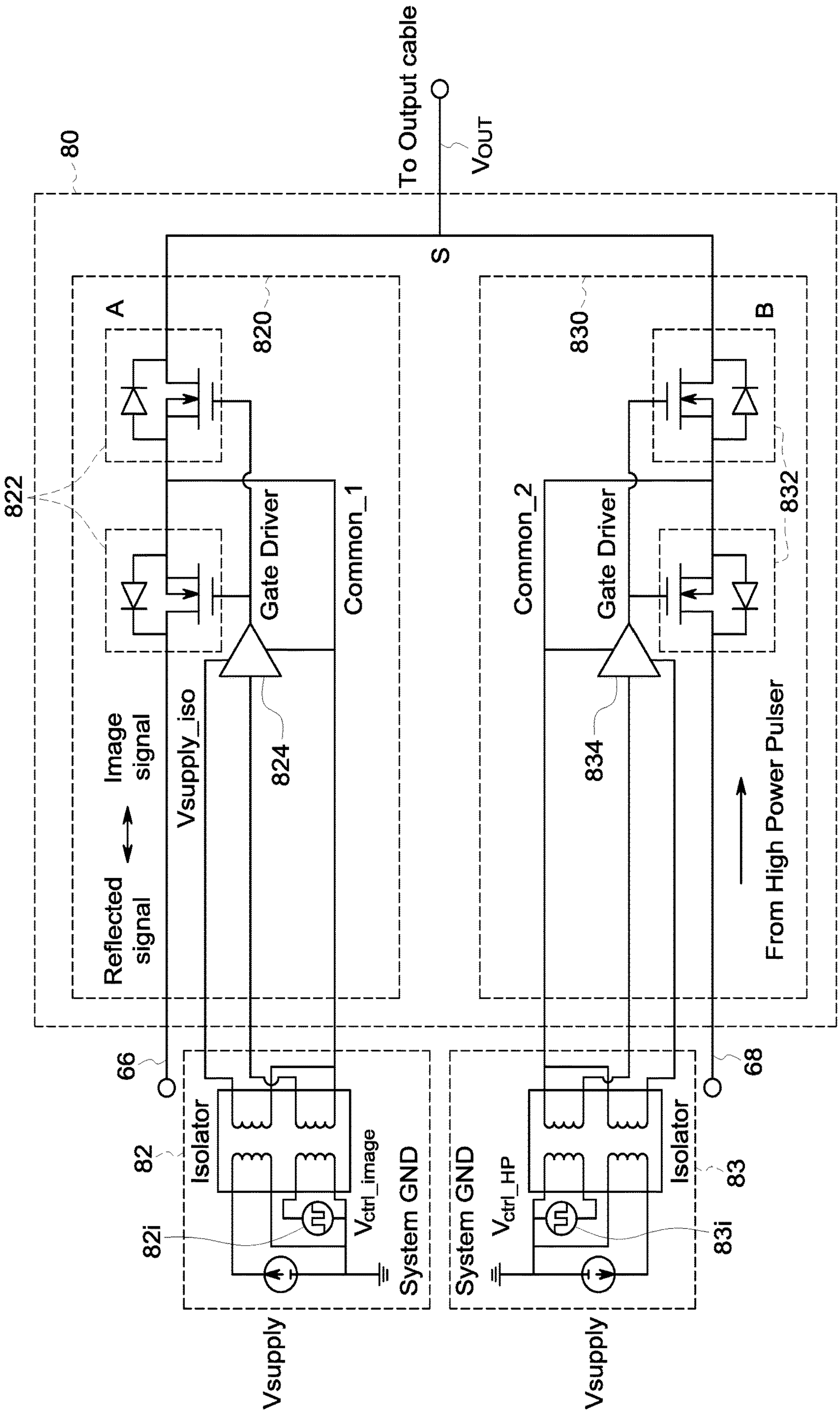

To Output cable
VOUT
80
S
A
820
822
Gate Driver
Common_1
Reflected signal
Image signal
Vsupply_iso
824
830
B
Common_2
Gate Driver
832
834
From High Power Pulser
66
68
Isolator
82
82i
Vctrl_image
System GND
Vsupply
System GND
Vctrl_HP
Isolator
83
83i
Vsupply

FIG. 5

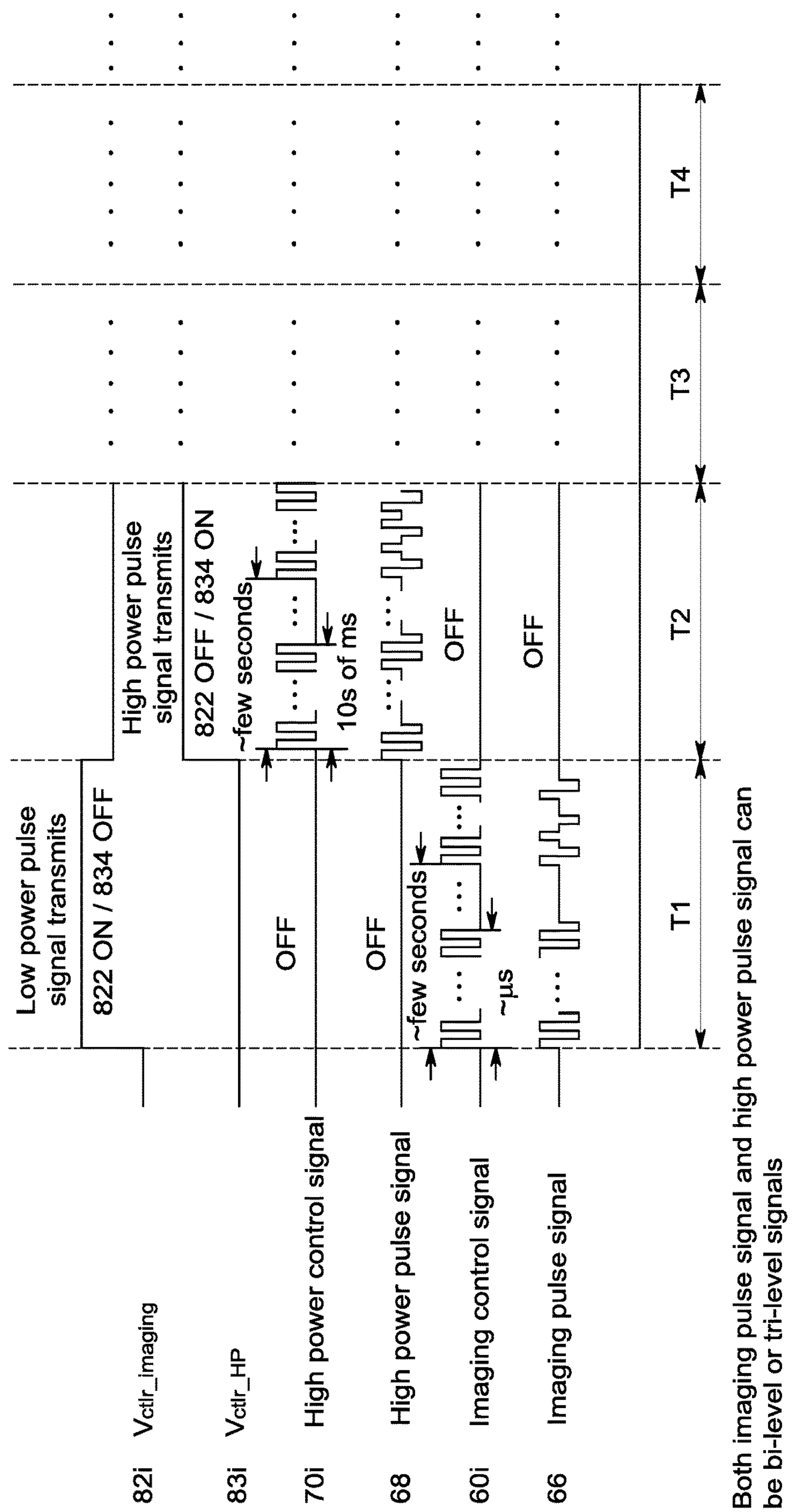

82i Vctlr_imaging
83i Vctlr_HP
70i High power control signal
68 High power pulse signal
60i Imaging control signal
66 Imaging pulse signal
Low power pulse signal transmits
822 ON / 834 OFF
High power pulse signal transmits
822 OFF / 834 ON
OFF
OFF
OFF
OFF
~few seconds
~few seconds
10s of ms
~µs
T1
T2
T3
T4
Both imaging pulse signal and high power pulse signal can be bi-level or tri-level signals

FIG. 6

FLEXIBLE ULTRASOUND SYSTEM FOR BOTH IMAGING AND HIGH POWER DELIVERY APPLICATIONS

GOVERNMENT RIGHTS STATEMENT

[0001] This invention was made with government support under NASA of the United States of America, under government contract number NNC09BA02B and subcontract number SPACEDOC 2013-003. The government may have certain rights in the invention.

BACKGROUND

[0002] The subject matter disclosed herein relates to ultrasound systems that may be utilized for diagnostic and/or therapeutic purposes. More particularly, present embodiments are directed to systems and methods that facilitate adjustment of a focus depth density and acoustic energy of an ultrasound probe between multiple positions while maintaining acoustic coupling.

[0003] The term ultrasound generally refers to cyclic sound pressure that has a frequency in a range that is higher than the upper limit of human hearing. A typical ultrasound frequency may include 1 to 20 megahertz. Ultrasound is frequently used for imaging purposes. For example, ultrasound is used in ultrasonography, which is a medical imaging technique that emits high frequency sound waves into a patient's body and detects echoes of the sound waves to produce images of features internal to the patient's body (e.g., blood flow images and intrauterine images). However, ultrasound may also be utilized to perform functions. For example, ultrasound for therapeutic purposes (e.g., stimulating a damaged muscle).

[0004] While there are numerous uses for ultrasound, a representative example may include a medical imaging application. In a typical ultrasound imaging application, sound waves are emitted into a patient's body from a probe and are reflected back to the probe when they hit boundaries. For example, some waves may reflect back to the probe upon reaching a boundary between fluid and tissue and other waves may reflect back to the probe upon reaching a boundary between tissue and bone. The probe detects the reflected waves and relays them to a monitor that utilizes the speed of the ultrasound and the time required to detect the reflected wave relative to the time of emission to calculate the distance from the probe to the reflecting surface. The distances and intensities of the detected waves may then be displayed to provide an image of the observed tissue. Relatively dense tissue may be distinguished from less dense tissue based on a difference in intensity because more dense tissue may reflect more ultrasound waves than less dense tissue.

BRIEF DESCRIPTION

[0005] There is set forth herein an ultrasound signal generating circuit having a control circuit which can include a control circuit having a control signal generating circuit; a low power signal driver circuit for providing a low power ultrasound signal; a high power signal driver circuit for providing a high power ultrasound signal; and a radiofrequency switch configured to transmit the low power ultrasound signal and the high power ultrasound signal to the ultrasound probe, wherein the radiofrequency switch isolates the low power signal driver circuit from the high power signal driver circuit; wherein the ultrasound signal generating circuit is configured so that the radiofrequency switch transmits an output low power ultrasound signal output by the low power signal driver circuit or an output high power ultrasound signal output by the high power signal driver circuit based on an output of the control signal generating circuit.

DRAWINGS

[0006] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0007] FIG. **1** is a block diagram of one element of ultrasound pulse generating system shown in the environment of an ultrasound system in which the ultrasound signal generating circuit to drive one or more ultrasound probes;

[0008] FIG. **2** is a flowchart illustrating a synchronization method that can be performed by an ultrasound signal generating circuit in one embodiment;

[0009] FIG. **3** is a physical from view of an ultrasound system according to one embodiment;

[0010] FIG. **4** illustrates a displayed user interface that can be displayed on a display of an ultrasound system according to one embodiment;

[0011] FIG. **5** is a schematic circuit diagram illustrating the output selection/transmission components of an ultrasound pulse generating circuit according to one embodiment;

[0012] FIG. **6** is a timing diagram illustrating various timing and control features of an ultrasound system.

DETAILED DESCRIPTION

[0013] There is illustrated in FIG. **1**, a circuit block diagram illustrating an ultrasound signal generating circuit **10**. Ultrasound signal generating circuit **10** can be incorporated in an ultrasound system **100**, wherein ultrasound signal generating circuit **10** drives one or more candidate ultrasound probes, such as one or more ultrasound probes **90**A-**90**Z. In one embodiment, there can be attached a single ultrasound probe **90**A e.g. a probe of candidate probes **90**A-**90**Z at a given time. As set forth herein, ultrasound signal generating circuit **10** can include features that facilitate operation of ultrasound system **100** in multiple operating modes including e.g. imaging operating modes of operation and therapeutic high power modes of operation. In general, when operating to support imaging low power modes of operation, ultrasound signal generating circuit **10** can output relatively lower power probe drive signals. When operating to support therapeutic high power modes of operation ultrasound signal generating circuit **10** can output relatively higher power probe drive signals. Ultrasound signal generating circuit **10** can include an associated signal processing circuit **4** for processing return signals. Signal processing circuit **4** can be active in an imaging low power modes of operation to process return signals attributed to reflected ultrasound signals reflected from target e.g. body tissue being subject to imaging. Return signals can be picked up by a transducer array of an attached ultrasound probe.

[0014] In one embodiment as set forth in FIG. **1**, ultrasound signal generating circuit **10** can include control circuit **20** and driver circuit **50**. Control circuit **20** in one embodiment can include control signal generator circuit **22** and selector circuit **24**, which selector circuit **24** in one embodiment can be provided by field programmable gate array (FPGA). Driver circuit **50** can include a low power signal driver circuit **60**, and high power signal driver circuit **70**, as well as radiofrequency (RF) switch **80**, and interface **86**. Low power signal driver circuit **60** can include a power supply **62** and pulse generator **64**. High power signal driver circuit **70** can include a power supply **72**, logically and physically separate from power supply **62** and pulse generator **64**. In a further aspect, ultrasound signal generating circuit **10** can include isolator circuits **82** and **83** for isolating driver circuit **50** from control circuit **20**, and can also include synchronization circuits **84** and **85** for synchronization of mode transitions performed by ultrasound signal generating circuit **10**. Operational aspects of synchronization circuits **84** and **85** are described further in reference to the flowchart of FIG. **2** illustrating a synchronization method that can be performed by ultrasound signal generating circuit **10**. "Low power" and "high power" are used as relative terms. Elements set forth herein prefaced with the terms "low" and "high" can alternatively be prefaced with the terms "first" and "second". For example, "low power signal driver circuit" can alternatively be termed a "first power signal driver circuit" and "high power signal driver circuit" can alternatively be termed a "second power signal driver circuit." In one embodiment, low power signal driver circuit **60** outputs relatively lower power probe drive signal than high power signal circuit **70**. In one embodiment, low power signal driver circuit **60** outputs relatively lower average power probe drive signal than high power signal circuit **70**. The lower power probe drive signal can be provided by a low power pulse signal as set forth herein. The higher power probe drive signal can be provided by a high power pulse signal as set forth herein. There is set forth herein a flexible ultrasound image system for both imaging and high power delivery applications.

[0015] At block **210** of method **200**, ultrasound signal generating circuit **10** e.g. by selector circuit **24**, can examine a current control signal generated by control signal generator circuit **22**. Control signal generator circuit **22** can be configured to generate control signals e.g. based on user defined data defined using a manually operating user interface and/or based on a probe currently attached to interface **86**.

[0016] For performance at block **210** in one embodiment, selector circuit **24** can examine a current control signal as received via control signal input signal line **22*i***. Based on the examining performed at block **210**, selector circuit **24** at block **220** to determine whether the currently active control signal specifies deactivating the currently activated signal driver circuit. In the operation of ultrasound signal generating circuit **10** one of low power signal driver circuit **60** and high power signal driver circuit **70** can be active.

[0017] Ultrasound signal generating circuit **10** can be operative to perform mode changes to transition modes of operation of ultrasound signal generating circuit **10**. In one aspect ultrasound signal generating circuit **10** can transition from a low power state in which low power signal driver circuit **60** is active and high power signal driver circuit **70** is inactive to a high power state in which high power signal driver circuit **70** is active and low power signal driver circuit **60** is inactive. In one aspect ultrasound signal generating circuit **10** can perform a state transition from a high power state in which high power signal driver circuit **70** is active and low power signal driver circuit **60** is in active to a low power state in which low power signal driver circuit **60** is active and high power signal driver circuit is inactive. Referring to blocks **210** and **220**, selector circuit **24** can execute blocks **210** and **220** iteratively in a loop, until the current control signal specifies a mode change.

[0018] On the determination that a currently active control signal specifies mode transition, selector circuit **24** can proceed to block **230**. Based on a current control signal specifying deactivating a currently activated signal driver circuit, selector circuit **24** can proceed to block **230** to perform deactivating the current active signal driver circuit e.g. can deactivate low power signal driver circuit **60** if low power signal driver circuit **60** is currently active or can deactivate high power signal driver circuit **70** if high power signal driver circuit **70** is currently active. Selector circuit **24** can communicate a deactivation signal via a signal line **60*i*** for deactivating low power signal driver circuit **60**.

[0019] For deactivating high power signal driver circuit **70**, selector circuit **24** can transmit a deactivation signal via signal line **70*i***. According to synchronization method **200**, selector circuit **24** can be operative to transmit signal driver circuit deactivating signals prior to transmitting signal driver circuit activation signals and can be restricted from transmitting an activation signal to activate a signal driver circuit until a time that selector circuit **24** confirms that a currently active signal driver circuit has been successfully deactivated.

[0020] At block **240**, selector circuit **24** can examine a driver signal transmission channel e.g. an appropriate one of transmission channel **66** or transmission channel **68** to ascertain whether the channel indicates that the drive signal has been removed from the channel. For performance of block **240**, selector circuit **24** can monitor an output received from an appropriate one of synchronization circuit **84** or **85**. An output from synchronization circuit **84** can be received via signal line **84*i*** and an output of synchronization circuit **85** can be received via signal line **85*i***. An output of synchronization circuit **84** can be monitored by selector circuit **24** in the case that low power signal driver circuit **60** is currently active and is being deactivated. An output from synchronization circuit **85** can be monitored in the case that high power signal driver circuit **70** is currently active and is being deactivated. Selector circuit **24** can be configured so that selector circuit **24** is restricted from transmitting an activation signal to activate a new signal driver circuit **60** or **70** until such time that selector circuit **24**, via monitoring of an output of synchronization circuit **84** or **85** confirms that a currently activated low power signal driver circuit **60** or high power signal driver circuit **70** has been successfully deactivated.

[0021] Referring to synchronization circuit **84** and synchronization circuit **85**, synchronization circuits **84** and **85** can include appropriate circuitry to sense whether low power pulse signal transmission channel **66** or high power pulse signal transmission channel **68** is currently transmitting a pulse signal for driving an ultrasonic probe. Synchronization circuits **84** and **85** can include appropriate current limiting circuitry so that current conducted through synchronization circuits **84** and **85** is reduced to safe low levels so as to avoid a negative effect on selector circuit **24**. Control circuit **20** including control signal generator circuit **22** and selector circuit **24** in one embodiment can be provided by digital circuitry that can be powered at low voltage levels e.g. 5 volt control voltage supply or less. In one embodiment, control signal generator circuit **22** can be provided by a processor based circuit. Selector circuit **24** can provided by an FPGA in communication with control signal generator circuit **22**.

[0022] Based on the appropriate one of transmission channel **66** or transmission channel **68** no longer transmitting a drive signal, selector circuit **24** can proceed to block **250** to perform activating a new signal driver circuit e.g. low power signal driver circuit **60** or high power signal driver circuit **70**. For performing block **250**, selector circuit **24** can transmit a trigger signal for changing the state of RF switch **80** e.g. from high power active to low power active or from low power active to high power active. At block **250**, selector circuit **24** can transmit one or more trigger signal for triggering switching of RF switch **80**. Selector circuit **24** can transmit a trigger signal provided by a low power mode activating control signal for activating low power signal driver circuit **60** via signal line **82***i* which trigger signal can be received by isolator circuit **82**, which can pass the trigger signal provided by a low power mode activating control signal for receipt by RF switch **80**. Selector circuit **24** can transmit a trigger signal provided by a high power mode activating control signal for activation of high power signal driver circuit **70** via signal line **83***i* for receipt by isolator circuit **83**, which isolator circuit **83** can pass the trigger signal provided by a high power mode activating control signal to RF switch **80**. At block **250**, selector circuit **24** via an appropriate one of signal lines **60***i* or **70***i* with an activation signal transmitted by selector circuit **24** to an appropriate one of low power signal driver circuit **60** or high power signal driver circuit **70** at block **250**. There can be further transmitted waveform information via signal line **60***i* or **70***i* that specifies e.g. pulse with frequency and/or amplitude information to the appropriate signal driver circuit **60** or **70**.

[0023] A physical form view of an ultrasound system **100** in one embodiment is illustrated in reference to FIG. **3**. Ultrasound system **100** can include one or more housing such as housing **110** that houses ultrasound signal generating circuit **10**. Housing **110** in one embodiment can support interface **86** (FIG. **1**) to which an ultrasound probe of the set of candidate ultrasounds probes **90A-90Z** can be attached. Ultrasound system **100** can also include a display **120** supported by one or more housing e.g. housing **110** and a keyboard **130** supported by one or more housing e.g. housing **110**.

[0024] A user interface **400** that can be displayed on display **120** is illustrated with reference to FIG. **4**. In one embodiment a user can use a user interface **400** to select modes of operation of ultrasound system **100**. A user of user interface **400** can be e.g. a healthcare provider user e.g. physician, physician assistant, nurse, or an individual using ultrasound system **100** for personal use.

[0025] Referring to user interface **400**, a user can use area **402** to select imaging low power modes of operation. A user can activate button **404** to initiate display of imaging low power mode menu options in area **406** and can select between imaging low power modes e.g. mode **1**, mode **2**, etc. using area **406**. A user can activate button **412** to initiate display of therapeutic high power mode selector area **414** and can select between different therapeutic high power modes e.g. therapeutic high power mode A, Mode B, etc. using area **414**. Using area **408** a user can select mixed modes of operation e.g. modes in which ultrasound system **100** can automatically transition between imaging low power mode operation and therapeutic high power mode operation. When a mixed mode is active ultrasound signal generating circuit **10** can automatically transition between states of operation e.g. between a low power state in which low power signal driver circuit **60** is active and high power signal driver circuit **70** is in active and a high power state in which high power signal driver circuit **70** is activate and low power signal driver circuit **60** is inactive. A user can activate button **420** to call up area **422** that displays indicators of various mixed operating modes e.g. Mixed Mode i and Mixed Mode ii, and a user can select between various mixed mode operating modes using area **422**. A user can activate a selected operating mode using activate button **426**. By way of its high rate switching operation RF switch **80** can facilitate a variety of mixed mode operations in which ultrasound system **100** can automatically and iteratively transition between a first state wherein low power signal driver circuit **60** is ON and high power signal driver circuit **70** is OFF and a second state wherein high power signal driver circuit **70** is ON and low power signal driver circuit **60** is OFF.

[0026] In one embodiment, a control signal that can be generated by control signal generator circuit **22** can be based on user defined mode selection data which can be defined by a user using a manually operated user interface **400** as set forth in reference to FIG. **4**.

[0027] In addition or alternatively, the control signal that can be generated by control signal generator circuit **22** can be based on a probe that is currently attached to interface **86** as set forth in FIG. **1**. For example, based on a first probe e.g. probe **90A** being attached to interface **86**, control signal generator circuit **22** can generate a first control signal. Based on a second probe e.g. probe **90Z** being attached to interface **86**, control signal generator circuit **22** can generate a second control signal. Ultrasound signal generating circuit **10** can be configured so that one ultrasound probe of a candidate set of ultrasound probes **90A-90Z** can be attached to interface **86** at a given time.

[0028] A set of probes e.g. probes **90A-90Z** can include one or more imaging probe and one or more therapeutic probe. Based on an imaging probe being attached to interface **86**, control signal generator circuit **22** can generate a control signal for initiating operation in an imaging low power mode. Based on a therapeutic probe being attached to interface **86**, control signal generator circuit **22** can generate a control signal for initiating operation in a therapeutic high power mode. A control signal initiating an imaging low power mode can initiate deactivating of high power signal driver circuit **70** is currently active and can initiate activating low power signal driver circuit **60**. A control signal initiating a therapeutic high power mode can initiate deactivating of low power signal driver circuit **60** if currently active and can initiate activating high power signal driver circuit **70**.

[0029] A set of probes **90A-90Z** can include one or more imaging probe adapted for use with an imaging low power mode of operation, one or more therapeutic probe adapted for use with a therapeutic high power mode of operation, and one or more mixed mode probe adapted for use with a mixed mode of operation in which ultrasound system **100** automatically transitions between and imaging low power mode and a therapeutic high power mode. In one embodiment, attachment of an imaging probe can restrict modes of operation that can be selected by a user. For example, referring to user interface **400**, on the attachment of an imaging probe, the modes depicted in area **410** and **418** of user interface **400** can be restricted and made not available for selection by a user. Similarly, on the attachment of a therapeutic probe, the modes of operation depicted in area **402** and **418** of user interface **400** can be restricted and not available for selection by a user. On the attachment of a mixed mode probe, which can include probe transducers adapted for use in any one of an imaging low power mode, a therapeutic high power mode, and a mixed mode, some modes of operation depicted in each of area **402**, **410** and **418** can be restricted and others made available for selection.

[0030] An imaging low power mode of operation can be provided by a non-harmonic imaging low power mode of operation or a harmonic imaging low power mode of operation. With non-harmonic imaging, ultrasound system **100** can transmit and receive a sound pulse of a specific frequency. The difference between the transmitted and returned signal is that the returned signal is less intense, losing strength as it passes through tissue. With harmonic imaging the signal returned by the tissue includes not only the transmitted "fundamental" frequency, but also signals of other frequencies. Most notably, the "harmonic" frequency, which is twice the fundamental frequency. Once this combined fundamental/harmonic signal is received, the ultrasound system separates out the two components and then processes the harmonic signal alone. Therapeutic operating modes can be performed with or without processing of a return signal. Therapeutic ultrasound probes of ultrasound probes **90**A-**90**Z can be specially adapted for a variety of alternative applications, e.g. physical therapy, hyperthermia, extracorporeal shock wave lithotripsy, intracorporeal lithotripsy high intensity focused ultrasound, harmonic scalpels, skin permeabilization, bone fracture healing.

[0031] Ultrasound probes **90-90**Z that are adapted for imaging typically include one or two dimensional arrays of ultrasound transducers. Linear ultrasound imaging transducer arrays can be provide in various array sizes, e.g. 64×1, 128×1, 256×1, 512×1. Two dimensional ultrasound imaging transducer arrays can be provide in various array sized e.g. 32×32, 64×64, 128×128, 256×256, 512×512. Ultrasound probes **90-90**Z that are adapted for therapeutic applications typically include a smaller number of larger scale transducers, and typically include from **1** to about 10 transducers. In general, when operating to support imaging low power modes of operation, ultrasound signal generating circuit **10** can output relatively lower power probe drive signals. When operating to support therapeutic high power modes of operation ultrasound signal generating circuit **10** can output relatively higher power probe drive signals. In typical imaging low power modes, low power signal driver circuit **60** can be operative to drive a transducer array of an imaging ultrasound probe to emit energy at an average energy rating of 5 W or less and in many cases 1 W or less. In typical therapeutic high power modes, circuit **70** can be operative to drive a transducer or transducer array of an imaging ultrasound probe to emit energy at an average energy rating of 5 W or more in some cases 50 W or more.

[0032] Further details of ultrasound signal generating circuit **10** in one embodiment are described in reference to FIG. **5**, illustrating various features in one embodiment of isolator circuit **82**, isolator circuit **83**, and RF switch **80**. RF switch **80** can include a low power transmission area **820** and a high power transmission area **830**. Low power transmission area **820** can include a transistor pair **822** provided by a power transistor pair and a gate driver **824**. High power transmission area **830** can include transistor pair **832** provided by a power transistor pair and a gate driver **834**. In one embodiment each of the first transistor pair **822** and the second transistor pair **832** can be configured to provide bi-directional power flow.

[0033] RF switch **80** can be configured so that when a gate driver signal controlling gate driver **824** is on, low power signal area **820** is active so that a pulse signal probe driven by low power signal driver circuit **60** for driving an attached ultrasound probe can be transmitted through RF switch **80**. RF switch **80** can be configured so that when a gate driver signal driving gate driver **834** is ON, high power area **830** is active so that RF switch **80** transmits the pulse signal provided by high power signal driver circuit **70** for driving an attached ultrasound probe. A gate driver signal controlling gate driver **824** can be provided by a trigger signal which trigger signal can be provided by a low power mode activating control signal transmitted by selector circuit **24** as previously set forth herein and transmitted via signal line **82***i* and received by isolator circuit **82** for transmission to gate driver **824**. A gate driver signal for driving gate driver **834** can be provided by a trigger signal which trigger signal can be provided by a high power mode activating control signal transmitted by selector circuit **24** via signal line **83***i* and received by isolator circuit **83** for transmission to gate driver **834**. Gate drivers **824** and **834** can be provided by analog gate drivers that are configured to amplify received control signals, which can include a low power mode activating control signal as received by gate driver **824** or a high power mode activating control signal as received by gate driver **834**. As set forth herein RF switch **80** can include a first power transistor pair **822** and a second power transistor pair **832**, wherein respective analog gate drivers **824** and **834** are used to amplify a control signal provided by respective isolator circuits **82** and **83** to drive the first power transistor pair **822** and the second power transistor pair **832**.

[0034] RF switch **80** can be configured to provide isolation between components and signals of low power signal driver circuit **60** and high power signal driver circuit **70**. Components of RF switch **80** providing isolation can include transistor pair **822** of low power areas **820** and transistor pair **832** of high power area **830**. RF switch **80** can provide isolation between low power signal driver circuit **60** and high power signal driver circuit **70**, e.g. isolation between propagating pulse signals (high or low power) and circuit elements of the inactive drive circuit side (low or high power).

[0035] Transistor pair **822** can be a high frequency low distortion power transistor configured with sources connected together in a back to back configuration and with gates and sources connected together and sources defining a middle (floating) point of the transistor pair. Transistor pair **822** can be configured so that when transistor pair is **822** turned on, a low impedance path is generated to ensure high frequency, low distortion transmission of low power ultrasound signals as well as return signal back from an attached ultrasound probe for processing by signal processing circuit **4**. RF switch **80** can be configured to provide isolation for signal processing circuit **4** from a high power pulse signal propagating on transmission channel **68** with good attenuation (e.g. 40 dB attenuation or more). RF switch **80** can be configured to transmit a return signal from an attached ultrasound probe with good linearity and low distortion to provide a low amplitude and low power return signals. Transistor pair **822** can be configured so that when transistor pair **822** is turned off, a high impedance path is generated to provide reliable isolation of output drive signals between high power signal driver circuit **70** and circuit elements of low power signal driver circuit **60** and the signal processing circuit **4**. High voltage power transistors that are e.g. Si based or GaN based can be used. A gate driver **824** which can be provided as a high frequency gate driver can be configured to drive transistor pair **822**.

[0036] Transistor pair **832** can be a high frequency low distortion power transistor pair configured with sources connected together in a back-to-back configuration and with gates and sources connected together and sources defining a middle (floating) point of the transistor pair. Transistor pair **832** can be configured so that when transistor pair **832** is turned on, a low impedance path is generated to ensure high frequency, low distortion transmission of high power ultrasound signals. Transistor pair **832** can be configured so that when transistor pair **832** is turned off, a high impedance path is generated to provide reliable isolation of output drive signals between high power signal driver circuit **70** and from circuit elements of low power signal driver circuit **60** as well as signal processing circuit **4**. High voltage power transistors that are e.g. Si based or GaN based can be used. A high frequency gate driver as **834** can be provided to drive transistor pair **822**.

[0037] Isolator circuit **82** and isolator circuit **83** can provide isolation between RF switch **80** and control circuit **20** so that components of control circuit **20** and control signals thereof are not negatively affected by pulse signals for driving an ultrasound probe propagating along transmission channel **66**, transmission channel **68** and/or RF switch **80**.

[0038] In one embodiment, isolator circuits **82** and **83** provide isolated supply voltage and isolated control signals for RF switch **80**. In one embodiment each power transistor pair **822** and **823** can be provided with a transistor source connected together in a back to back configuration. For proper operation with such a configuration, the sources of each power transistor pair **822** and **832** can be connected at a common floating voltage node, e.g. Common_**1** and Common_**2**. Floating voltages at the common floating voltage node (Common_**1** or Common_**2**) can thus include the line voltage of low power pulse signal transmission channel **66** or high power pulse signal transmission channel **68** when the respective transistor pair (**822** or **823**) is ON.

[0039] Isolator circuits **82** and **83** can be provided to input respective control signals to a respective transistor pairs **822** and **823** in a manner that avoids tying a transistor terminal to system ground (which would then tie drive signals to ground). An output of each isolator circuit **82** and **83** can be output to a floating voltage common node, Common_**1** and Common_**2**. The floating voltage common node Common_**1** can be connected to sources of first and second transistors defining transistor pair **822**. The floating voltage Common_**2** can be connected to sources of first and second transistors defining transistor pair **832**. Connected sources of each transistor pair **822** and **832** can thus be configured to propagate the line voltage of the transmission channel (transmission channel **66** or transmission channel **68**) associated to the transistor pair (**822** or **823**) when the transistor pair (**822** or **832**) is ON. Transistor pair **822** can include connected sources and gates and transistor pair **832** can include connected sources and gates. Isolator circuits **82** and **83** can include low voltage isolation transformers in one embodiment.

[0040] RF switch **80** in one embodiment can be provided by a single pole double throw switch. In one embodiment, RF switch **80** can be provided by a bidirectional RF switch. RF switch **80** can be provided to be high power handling e.g. in one embodiment can handle power loads of 1 W or more and other embodiments can handle power loads of 5 W or more and in another embodiment can handle power loads of 100 W or more. In one embodiment, RF switch **80** can be provided to have low resistance and can be provided to feature low conduction loss. In one embodiment, RF switch **80** can be a low distortion RF switch. In one embodiment, RF switch **80** can be a high speed RF switch. In one embodiment, RF switch **80** can provide a wide bandwidth.

[0041] As set forth in the embodiment described herein in reference to FIG. **5**, RF switch **80** can include custom designed analog circuit components. In one embodiment, RF switch **80** can include a diode T/R bridge. In one embodiment, RF switch **80** include a PIN diode switch. In one embodiment, RF switch **80** can include a relay, such as be provided by a G6K-2F-RF relay of the type available from OMRON. In one embodiment, RF switch **80** can include a MEMS relay. In one embodiment, RF switch **80** can include an OTS analog switch.

[0042] Timing features of ultrasound system **100** are described with reference to the timing diagram of FIG. **6**. At time period T**1**, an imaging low power mode activating control signal on signal line **82***i* can be ON to drive transistor pair **822** ON so that an imaging low power mode is activated. At time period T**1**, a high power mode activating control signal on signal line **83***i* can be OFF to drive transistor pair **832** OFF, so that a high power mode is in a deactivated state. At time period T**1** a high power mode activating control signal on signal line **70***i* can be OFF and with transistor pair **832** OFF, a high power drive signal can be absent from high power drive signal transmission channel. At time period T**1** an imaging low power mode activating control signal on signal line **60***i* can be ON and with transistor pair **822** ON a low power drive signal can be propagating on low power pulse signal transmission channel **66**.

[0043] At time period T**2**, an imaging low power mode activating control signal on signal line **82***i* can be OFF to drive transistor pair **822** OFF so that an imaging low power mode is in a deactivated state. At time period T**2**, a high power mode activating control signal on signal line **83***i* can be ON to drive transistor pair **832** ON to activate a high power mode. At time period T**2** high power mode activating control signal on signal line **70***i* can be ON and with transistor pair **832** ON for activating a high power mode a high power pulse signal for driving an ultrasound probe can be propagating on high power pulse signal transmission channel **68**. At time period T**2** an imaging low power mode activating control signal on signal line **60***i* can be OFF and with transistor pair **822** OFF a low power pulse signal can be absent from low power pulse signal transmission channel **66**.

[0044] At time period T**3**, the states indicated for lines **82***i*, **83***i*, **70***i*, **68**, **60***i*, **66** during time period T**1** can be repeated. At time T**4**, the states indicated for lines **82***i*, **83***i*, **70***i*, **68**, **60***i*, **66** can during time period T**3** can be repeated. The states of lines **82***i*, **83***i*, **70***i*, **68**, **60***i*, **66** can transition between the Time T**1** states and the time T**2** states iteratively and indefinitely. In one embodiment the state transitions between times T**1** and T**2**, and T**2** and T**3**, and T**3** and T**4** etc. can be in response to a user action e.g. configuration data entered into manually operated user interface **400** (FIG. **4**) or a new probe attached to interface **86** (FIG. **4**). In one embodiment, the state transitions between time periods T**1** and T**2**, and time periods T**2** and T**3**, and T**3** and T**4** etc. can be automated, e.g. in a described Mixed Mode (FIG. **4**) the states of lines **82***i*, **83***i*, **70***i*, **68**, **60***i*, **66** can iteratively and automatically transition between the time period T**1** states and time period T**2** states. During periods in which an imaging low power mode is active, e.g. time period T**1** and time period T**3**, T**5** etc. signal processing circuit **4** can be receiving and processing a return signal attributable to a reflected ultrasound signal. In some embodiments timing of an output of a low power pulse signal output to transmission channel **66** can be coordinated with active periods of signal processing circuit **4**. For example time periods T**1**, T**3**, T**5** etc. in some embodiments can be characterized by stop periods wherein output of a low power pulse signal by low power signal driver circuit **60** (FIG. **1**) for driving an ultrasound probe is stopped temporarily and wherein during the stop periods receipt of a return signal by signal processing circuit **4** is performed. In some embodiments signal processing circuit **4** can be active without low power signal driver circuit **60** being stopped. For example signal processing circuit **4** in some embodiments can filter an output low power pulse signal propagating on low power pulse signal transmission channel **66** that includes return signal components and can process the return signal components.

[0045] This written description uses examples to disclose the invention, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[0046] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the various embodiments without departing from their scope. While the dimensions and types of materials described herein are intended to define the parameters of the various embodiments, they are by no means limiting and are merely exemplary. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the various embodiments should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Forms of term "based on" herein encompass relationships where an element is partially based on as well as relationships where an element is entirely based on. Forms of the term "defined" encompass relationships where an element is partially defined as well as relationships where an element is entirely defined. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. § 112, sixth paragraph, unless and until such claim limitations expressly use the phrase "means for" followed by a statement of function void of further structure. It is to be understood that not necessarily all such objects or advantages described above may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the systems and techniques described herein may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein.

[0047] While the invention has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. Additionally, while various embodiments of the invention have been described, it is to be understood that aspects of the disclosure may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

1. An ultrasound signal generating circuit comprising:

a control circuit having a control signal generating circuit;

a low power signal driver circuit for providing a low power pulse signal;

a high power signal driver circuit for providing a high power pulse signal; and

a radiofrequency switch configured to transmit the low power pulse signal and the high power pulse signal to an ultrasound probe for driving the ultrasound probe, wherein the radiofrequency switch isolates the low power signal driver circuit from the high power signal driver circuit;

wherein the ultrasound signal generating circuit is configured so that the radiofrequency switch transmits an output low power pulse signal output by the low power signal driver circuit or an output high power pulse output by the high power signal driver circuit based on an output of the control signal generating circuit.

2. The ultrasound signal generating circuit of claim **1**, wherein the low power signal driver circuit outputs the low power pulse signal to a low power pulse signal transmission channel, and wherein the high power signal driver circuit outputs the high power pulse signal to a high power pulse signal transmission channel, wherein the radiofrequency switch outputs a propagating signal propagating on the low power pulse signal transmission channel or propagating signal propagating on the high power pulse signal transmission channel based on the output of the control signal generating circuit.

3. The ultrasound signal generating circuit of claim 1, wherein the ultrasound signal generating circuit includes an isolator circuit to isolate the radiofrequency switch from the control circuit.

4. The ultrasound signal generating circuit of claim 1, wherein the ultrasound signal generating circuit includes an isolator circuit to isolate the radiofrequency switch from the control circuit, wherein the isolator signal is configured to output a floating voltage control signal to the radiofrequency switch based on a control signal received from the control circuit.

5. The ultrasound signal generating circuit of claim 1, wherein the control circuit synchronizes switching between a first mode and a second mode by transmitting a deactivation signal to deactivate the a low power signal driver circuit, sensing a channel signal using a amplitude limiter for determining whether the low power signal driver circuit has been deactivated, and responsively to the determining transmitting an activation signal to activate the low power signal driver circuit, wherein the control circuit is restricted from transmitting the activation signal unless by the determining it is determined that the low power signal driver circuit has been deactivated.

6. The ultrasound signal generating circuit of claim 1, wherein an output of the radiofrequency switch defines an output of the ultrasound signal generating circuit.

7. The ultrasound signal generating circuit of claim 1, configured for receipt of an ultrasound probe of a candidate set of ultrasound probes, wherein the control signal generating circuit outputs a first control signal based on a first ultrasound transducer probe being attached to the ultrasound signal generating circuit, and wherein the control signal generating circuit outputs a second control signal based on second ultrasound probe being attached to the ultrasound signal generating circuit.

8. The ultrasound signal generating circuit of claim 1, wherein a control signal output by the control signal generating circuit is based on user defined data input by a user using a manually operated user interface.

9. The ultrasound signal generating circuit of claim 1, wherein a control signal output by the control signal generating circuit is based on an ultrasound transducer probe attached to the ultrasound signal generating circuit, and wherein the control signal is based on user defined data input by a user using a manually operated user interface.

10. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch is a single pole double throw switch.

11. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch includes a first power transistor pair and a second power transistor pair, the first power transistor pair connected in a back to back configuration characterized by sources of transistors defining the first power transistor pair being connected together, the second power transistor pair connected in a back to back configuration characterized by sources of transistors defining the second power transistor pair being connected together, wherein the first power transistor pair transmits the low power ultrasound signal based on the first power transistor pair being in an ON state, and wherein the second transistor pair transmits the high power ultrasound signal based on the second transistor pair being in an ON state.

12. The ultrasound signal generating circuit of claim 11, wherein the first power transistor pair and the second power transistor pair are provided by MOSFETs.

13. The ultrasound signal generating circuit of claim 11, wherein a transistor of the first power transistor pair is a transistor selected from the group consisting of silicon based MOSFET and a GaN based MOSFET.

14. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch includes a first power transistor pair and a second power transistor pair, wherein each of the first power transistor pair and the second power transistor pair are configured to provide bi-directional power flow.

15. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch includes a first power transistor pair and a second power transistor pair, the first power transistor pair having sources connected together and gates connected together, the second power transistor pair having sources connected together and gates connected together, wherein the first power transistor pair transmits the low power ultrasound signal based on the first power transistor pair being in an ON state, and wherein the second transistor pair transmits the high power ultrasound signal based on the second transistor pair being in an ON state.

16. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch includes a power transistor pair, wherein sources of transistors defining the transistor pair are connected at a common node configured as a floating voltage node.

17. The ultrasound signal generating circuit of claim 1, wherein the ultrasound signal generating circuit includes an isolator circuit to isolate the radiofrequency switch from the control circuit, wherein the isolator circuit includes a low voltage isolator transformer.

18. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch transmits a return signal attributable to a reflected ultrasound signal.

19. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch transmits a return signal attributable to a reflected ultrasound signal to a signal processing circuit based on the first power transistor pair being in an ON state.

20. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch includes a first power transistor pair and a second power transistor pair, and wherein respective analog gate drivers are used to amplify a control signal provided by respective isolator circuits to drive the first power transistor pair and the second power transistor pair.

21. The ultrasound signal generating circuit of claim 1, wherein the radiofrequency switch includes a power transistor pair, and wherein sources of transistors defining the transistor pair are connected at a common node configured as a floating voltage node, wherein the ultrasound signal generating circuit includes an isolator circuit to isolate the radiofrequency switch from the control circuit, wherein the isolator signal is configured to output a floating voltage control signal to common node based on a control signal received from the control circuit.

22. The ultrasound signal generating circuit of claim 1, wherein the ultrasound signal generating circuit includes an isolator circuit to isolate the radiofrequency switch from the control circuit, wherein the radiofrequency switch includes a first power transistor pair and a second power transistor

pair, the first power transistor pair connected in a back to back configuration characterized by sources of transistors defining the first power transistor pair being connected together, the second power transistor pair connected in a back to back configuration characterized by sources of transistors defining the second power transistor pair being connected together, wherein the first power transistor pair transmits the low power ultrasound signal based on the first power transistor pair being in an ON state, and wherein the second transistor pair transmits the high power ultrasound signal based on the second transistor pair being in an ON state.

23. The ultrasound signal generating circuit of claim **1**, wherein the ultrasound signal generating circuit includes an isolator circuit to isolate the radiofrequency switch from the control circuit, wherein the radiofrequency switch includes a first power transistor pair and a second power transistor pair, the first power transistor pair having sources connected together and gates connected together, the second power transistor pair having sources connected together and gates connected together, wherein the first power transistor pair transmits the low power ultrasound signal based on the first power transistor pair being in an ON state, and wherein the second transistor pair transmits the high power ultrasound signal based on the second transistor pair being in an ON state.

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摘要(译)

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