US009877699B2

(12) United States Patent
Chiang et al.

(10) Patent No.: US 9,877,699 B2
(45) Date of Patent: Jan. 30, 2018

(54) **TABLET ULTRASOUND SYSTEM**

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(73) Assignee: **Teratech Corporation**, Burlington, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/037,106**

(22) Filed: **Sep. 25, 2013**

(65) **Prior Publication Data**

US 2014/0121524 A1 May 1, 2014

Related U.S. Application Data

(63) Continuation-in-part of application No. PCT/US2013/033941, filed on Mar. 26, 2013, which

(Continued)

(51) **Int. Cl.**
A61B 8/00 (2006.01)
A61B 8/08 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 8/4427*** (2013.01); ***A61B 8/0841*** (2013.01); ***A61B 8/0883*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G06F 3/0488; G06F 3/041; G06F 3/0486; G06F 3/04886; G06F 19/3406;
(Continued)

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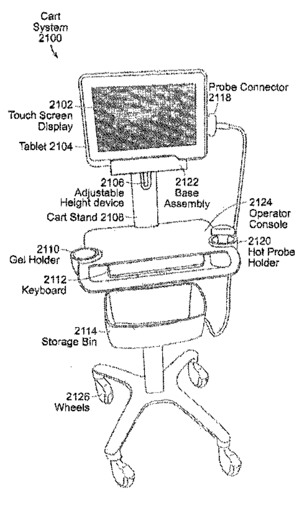
Primary Examiner — Sanjay Cattungal
(74) *Attorney, Agent, or Firm* — McCarter & English, LLP

(57) **ABSTRACT**

Exemplary embodiments provide systems and methods for portable medical ultrasound imaging. Preferred embodiments utilize a tablet touchscreen display operative to control imaging and display operations without the need for using traditional keyboards or controls. Certain embodiments provide ultrasound imaging system in which the scan head includes a beamformer circuit that performs far field sub array beamforming or includes a sparse array selecting circuit that actuates selected elements. Exemplary embodiments also provide an ultrasound engine circuit board including one or more multi-chip modules, and a portable medical ultrasound imaging system including an ultrasound engine circuit board with one or more multi-chip modules. Exemplary embodiments also provide methods for using a hierarchical two-stage or three-stage beamforming system,

(Continued)



three dimensional ultrasound images which can be generated in real-time.

59 Claims, 56 Drawing Sheets

Related U.S. Application Data

is a continuation-in-part of application No. 13/838,694, filed on Mar. 15, 2013.

(60) Provisional application No. 61/615,627, filed on Mar. 26, 2012, provisional application No. 61/704,254, filed on Sep. 21, 2012.

(51) **Int. Cl.**

G01S 7/52	(2006.01)
G06F 3/0488	(2013.01)
H01L 25/065	(2006.01)
G06F 19/00	(2011.01)
A61B 8/13	(2006.01)
A61B 8/06	(2006.01)
G01S 15/89	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 8/0891*** (2013.01); ***A61B 8/4405*** (2013.01); ***A61B 8/4477*** (2013.01); ***A61B 8/4483*** (2013.01); ***A61B 8/461*** (2013.01); ***A61B 8/462*** (2013.01); ***A61B 8/463*** (2013.01); ***A61B 8/465*** (2013.01); ***A61B 8/467*** (2013.01); ***A61B 8/468*** (2013.01); ***A61B 8/469*** (2013.01); ***A61B 8/5207*** (2013.01); ***A61B 8/56*** (2013.01); ***A61B 8/565*** (2013.01); ***G01S 7/52019*** (2013.01); ***G01S 7/52023*** (2013.01); ***G01S 7/52074*** (2013.01); ***G01S 7/52082*** (2013.01); ***G01S 7/52084*** (2013.01); ***G01S 15/8925*** (2013.01); ***G06F 3/0488*** (2013.01); ***G06F 3/04883*** (2013.01); ***G06F 19/321*** (2013.01); ***G06F 19/3406*** (2013.01); ***H01L 25/0657*** (2013.01); *A61B 8/06* (2013.01); *A61B 8/08* (2013.01); *A61B 8/13* (2013.01); *A61B 8/4444* (2013.01); *A61B 8/54* (2013.01); *G01S 15/8979* (2013.01); *H01L 2224/32145* (2013.01); *H01L 2224/32245* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/73265* (2013.01); *H01L 2924/181* (2013.01)

(58) **Field of Classification Search**

CPC . G06F 19/321; G06F 3/04883; A61B 8/4427; A61B 8/565; A61B 8/468; A61B 8/469; A61B 8/465; A61B 8/462; A61B 8/56; A61B 8/463; A61B 8/467; A61B 8/461; A61B 8/5207; A61B 8/0883; A61B 8/0891; A61B 8/4483; A61B 8/4405; A61B 8/4477; A61B 8/08; H01L 25/0657; H01L 2924/181; H01L 2224/32245; H01L 2224/48091; H01L 2224/32145; H01L 2224/73265; G01S 15/8925; G01S 7/52023; G01S 7/5201; G01S 7/52074; G01S 7/52084

USPC 600/437–469

See application file for complete search history.

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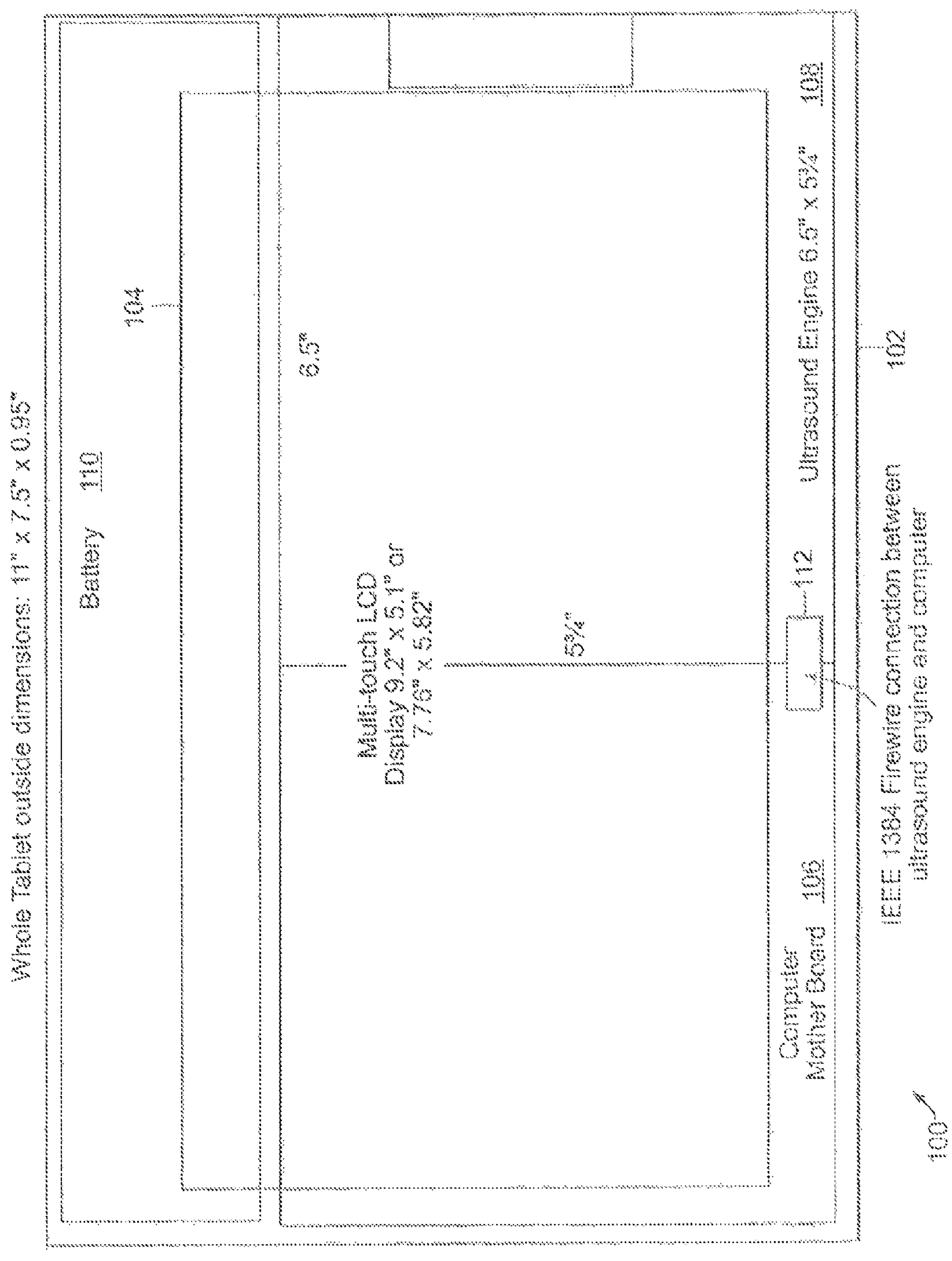
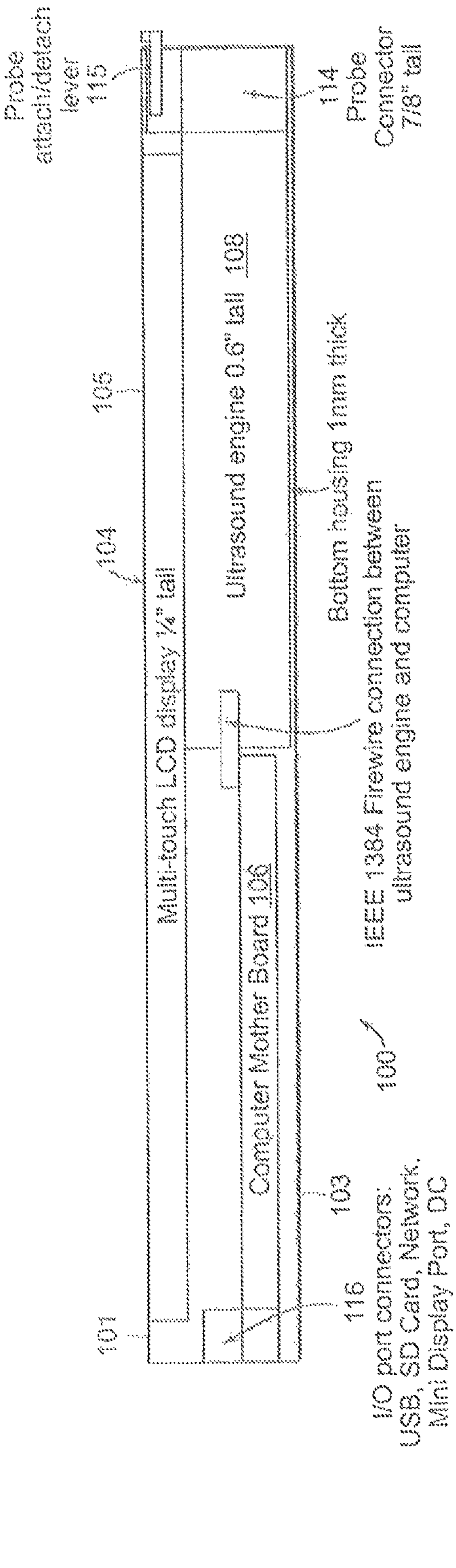

Whole Tablet outside dimensions: 11" x 7.5" x 0.95"
Battery 110
104
6.5"
Multi-touch LCD
Display 9.2" x 5.1" or
7.76" x 5.82"
5¾"
Computer
Mother Board 106
Ultrasound Engine 6.5" x 5¾" 108
102
112
IEEE 1394 Firewire connection between
ultrasound engine and computer
100

FIG. 1


Probe attach/detach lever 115
114 Probe Connector 7/8" tall
105
104
Multi-touch LCD display ¼" tall
Ultrasound engine 0.6" tall 108
Bottom housing 1mm thick
IEEE 1384 Firewire connection between ultrasound engine and computer
Computer Mother Board 106
100
103
101
116
I/O port connectors: USB, SD Card, Network, Mini Display Port, DC power input
FIG. 2A

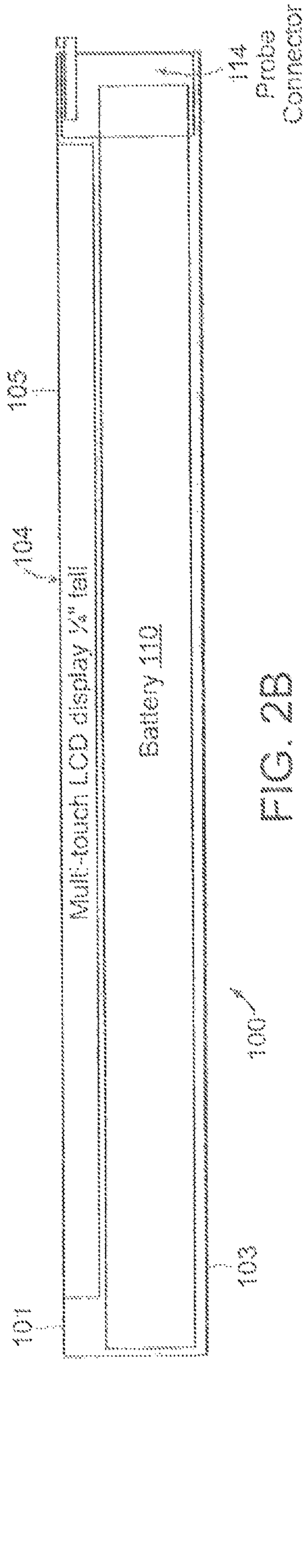

114 Probe Connector
105
104
Multi-touch LCD display ¼" tall
Battery 110
100
103
101
FIG. 2B

FIG. 3AA

302

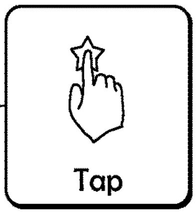


FIG. 3AB

304

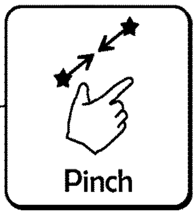


FIG. 3AC

306

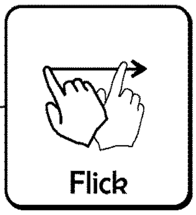


FIG. 3AD

308

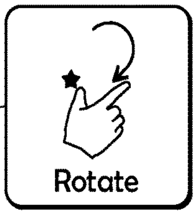


FIG. 3AE

310

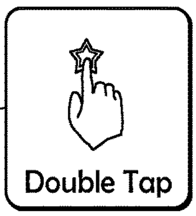


FIG. 3AF

312

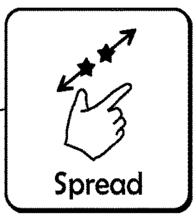


FIG. 3AG

314

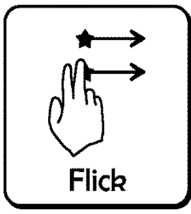


FIG. 3AH

316

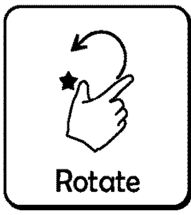


FIG. 3AI

318

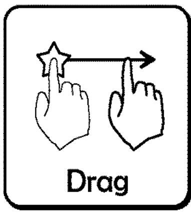


FIG. 3AJ

320

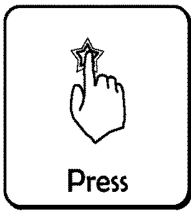


FIG. 3AK

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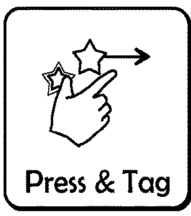


FIG. 3AL

324

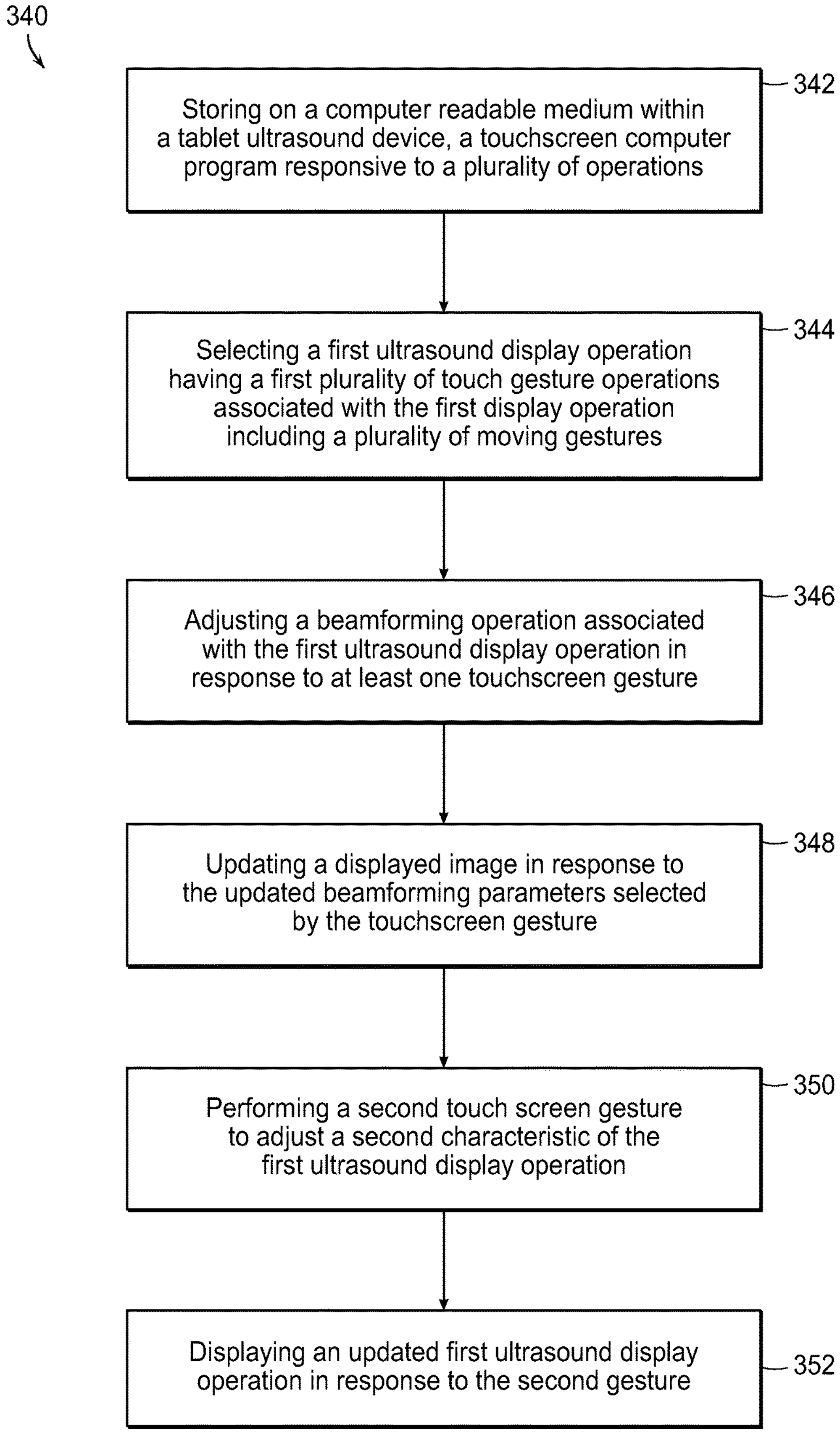

340
Storing on a computer readable medium within a tablet ultrasound device, a touchscreen computer program responsive to a plurality of operations
342
Selecting a first ultrasound display operation having a first plurality of touch gesture operations associated with the first display operation including a plurality of moving gestures
344
Adjusting a beamforming operation associated with the first ultrasound display operation in response to at least one touchscreen gesture
346
Updating a displayed image in response to the updated beamforming parameters selected by the touchscreen gesture
348
Performing a second touch screen gesture to adjust a second characteristic of the first ultrasound display operation
350
Displaying an updated first ultrasound display operation in response to the second gesture
352

FIG. 3B

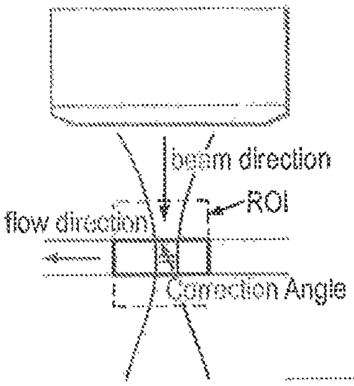


FIG. 3C

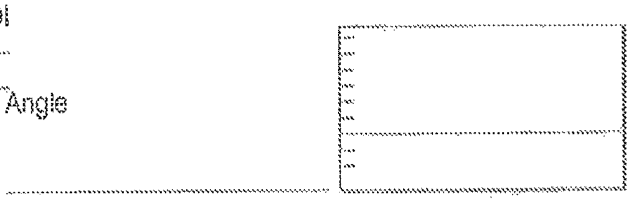


FIG. 3D

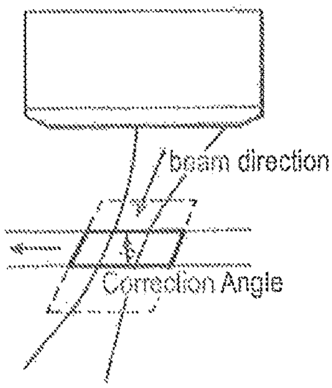


FIG. 3E

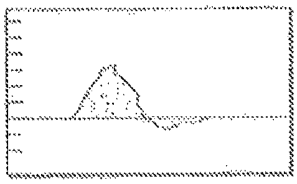


FIG. 3F

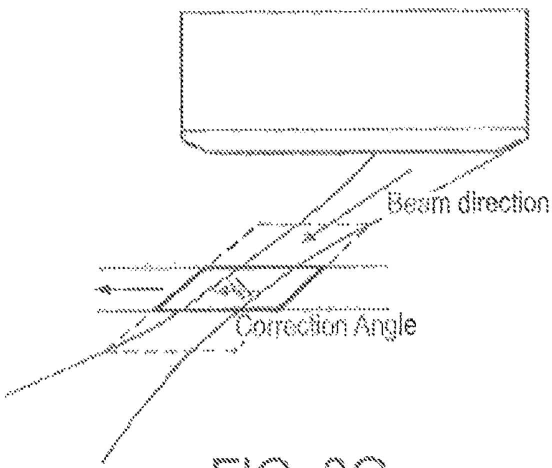


FIG. 3G

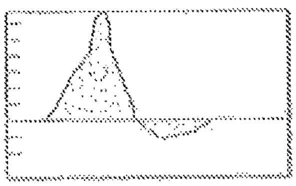


FIG. 3H

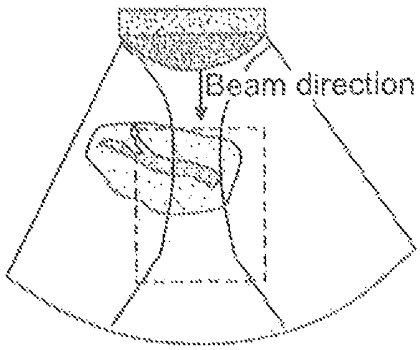


FIG. 3I

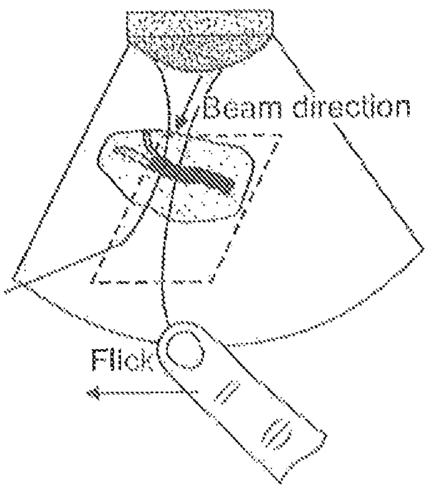


FIG. 3J

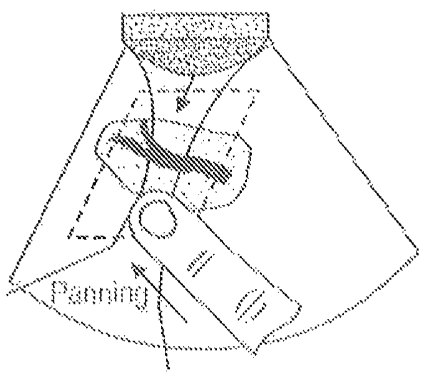


FIG. 3K

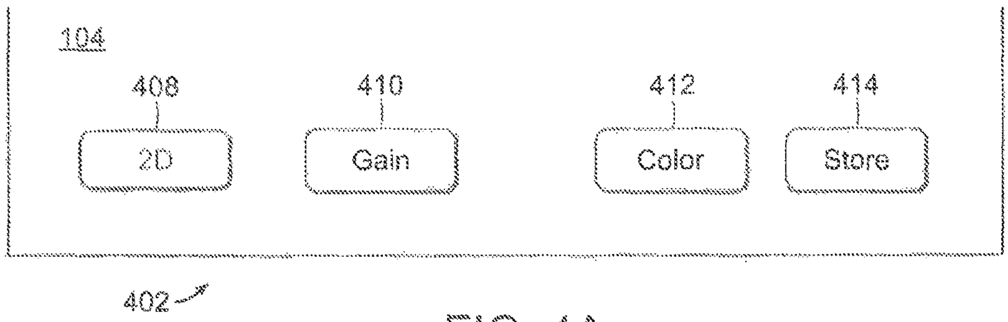


FIG. 4A

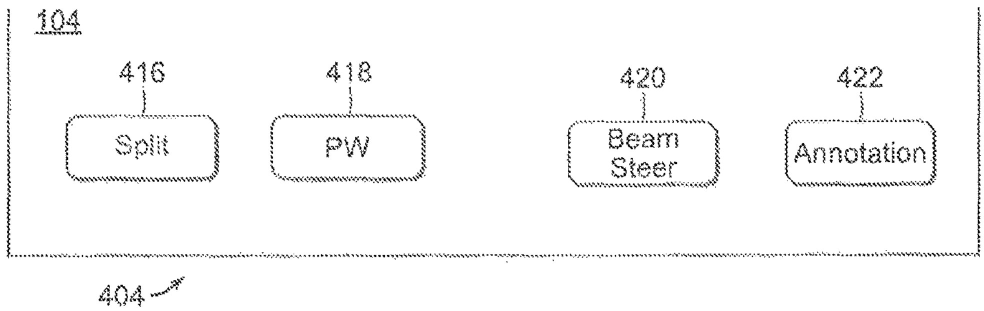


FIG. 4B

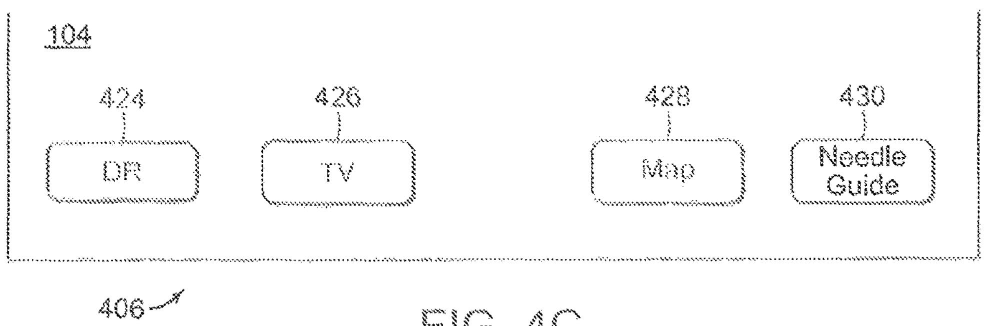


FIG. 4C

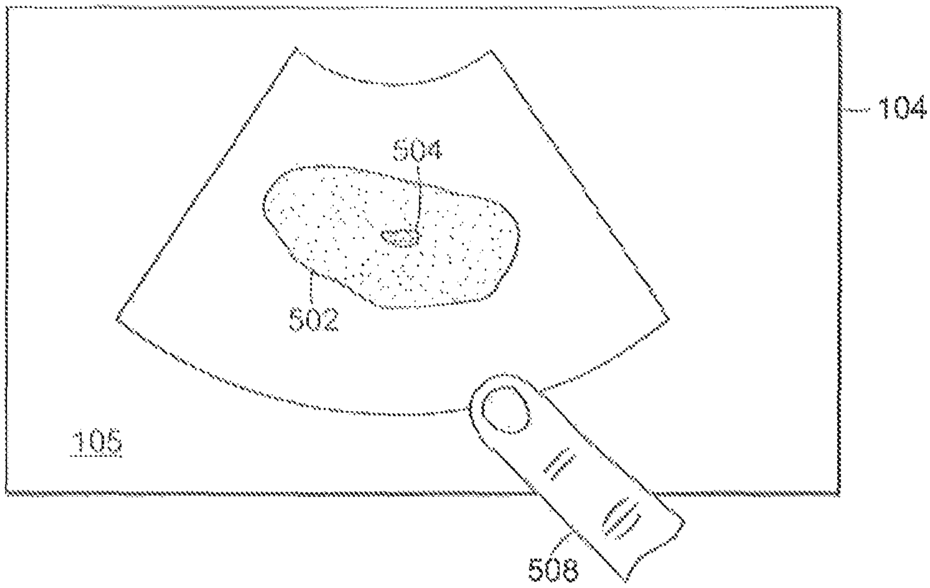


FIG. 5A

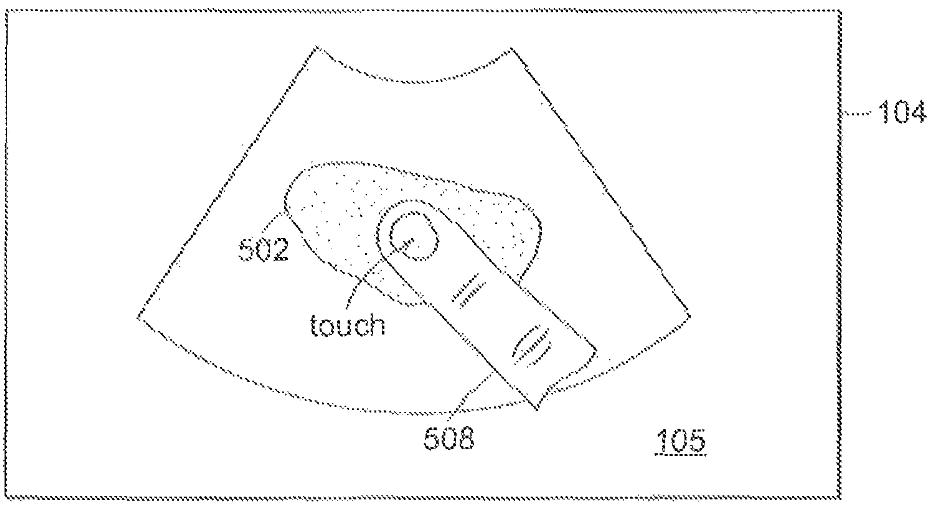


FIG. 5B

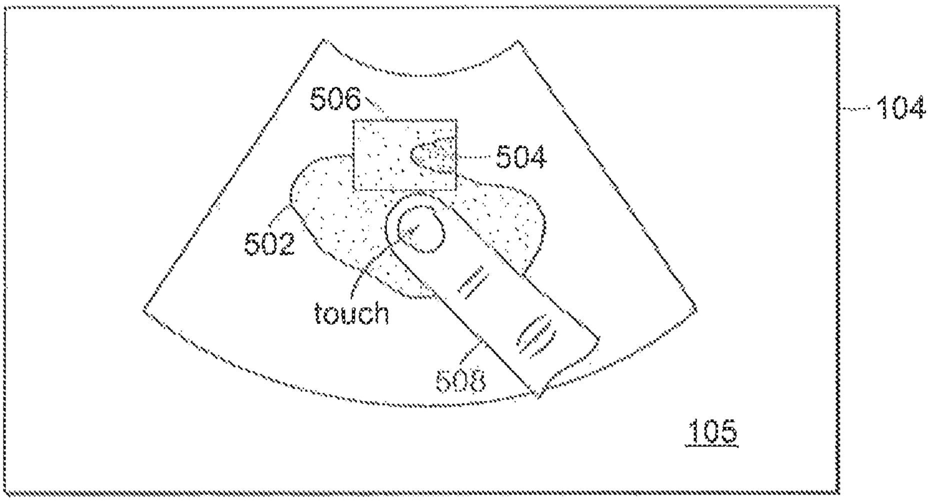


FIG. 5C

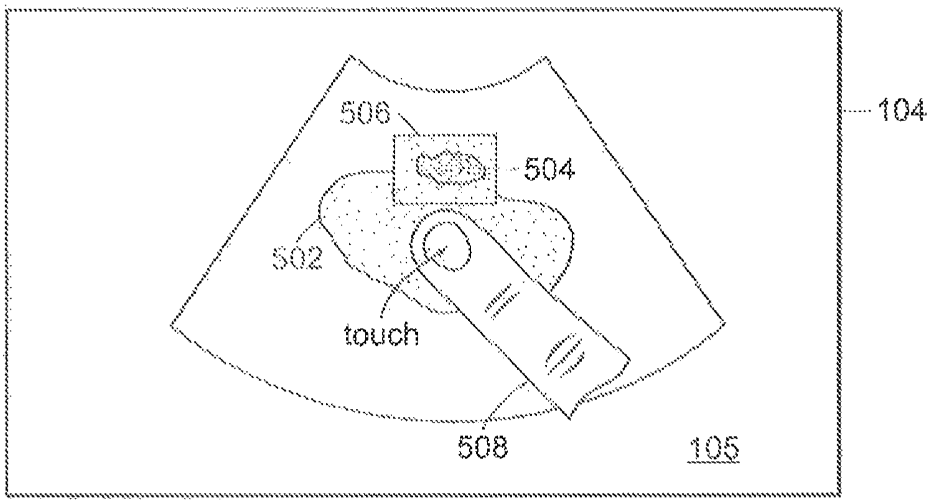


FIG. 5D

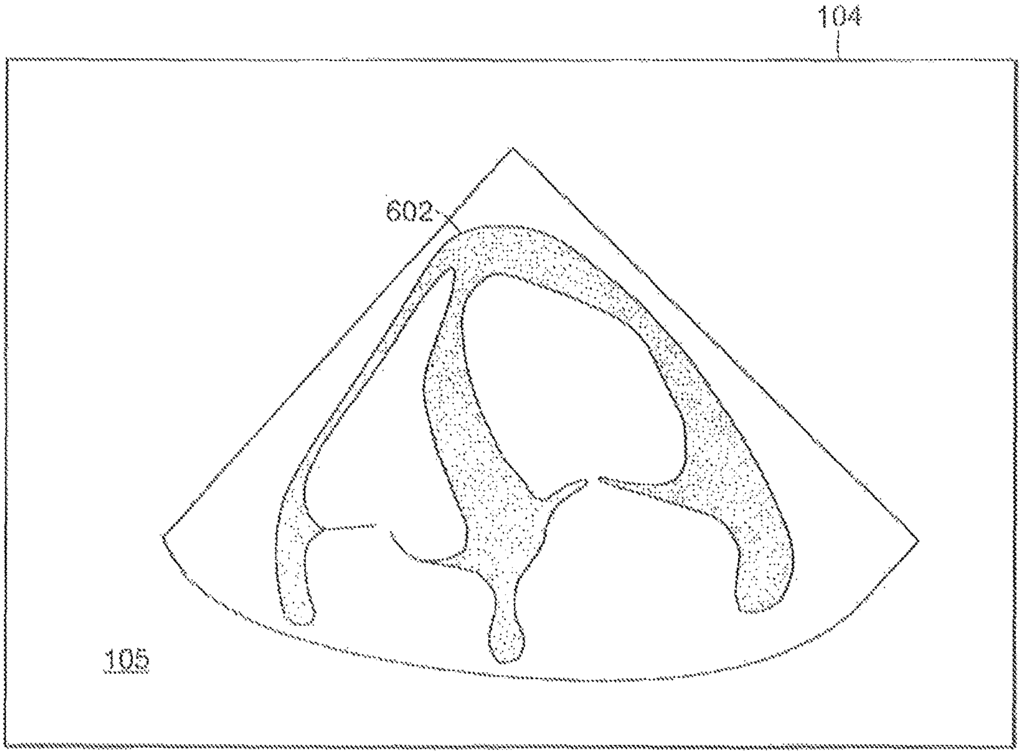


FIG. 6A

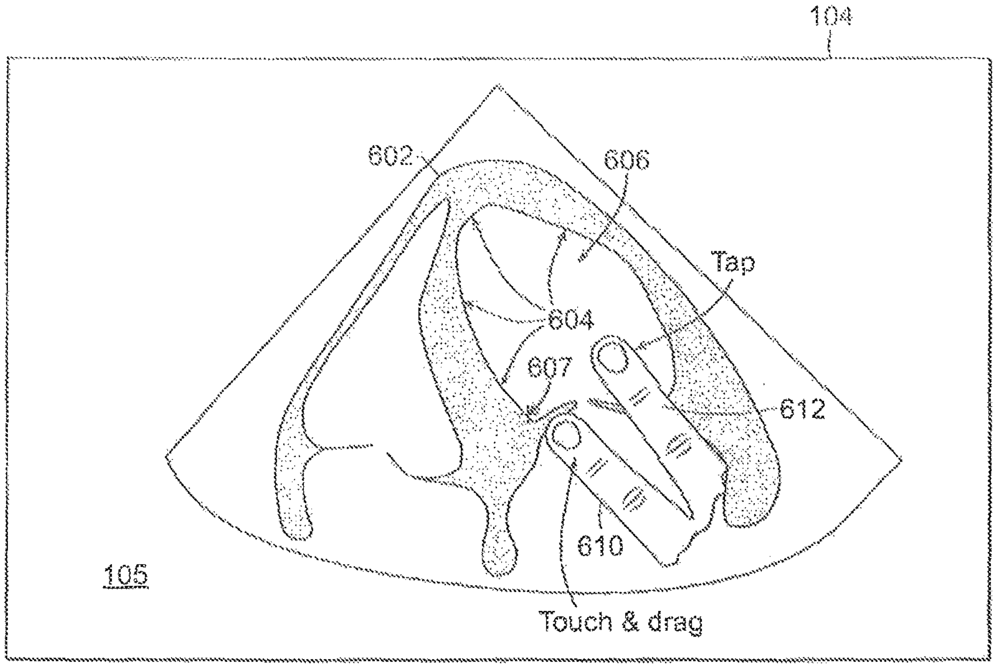

104
602
606
Tap
604
607
612
610
105
Touch & drag

FIG. 6B

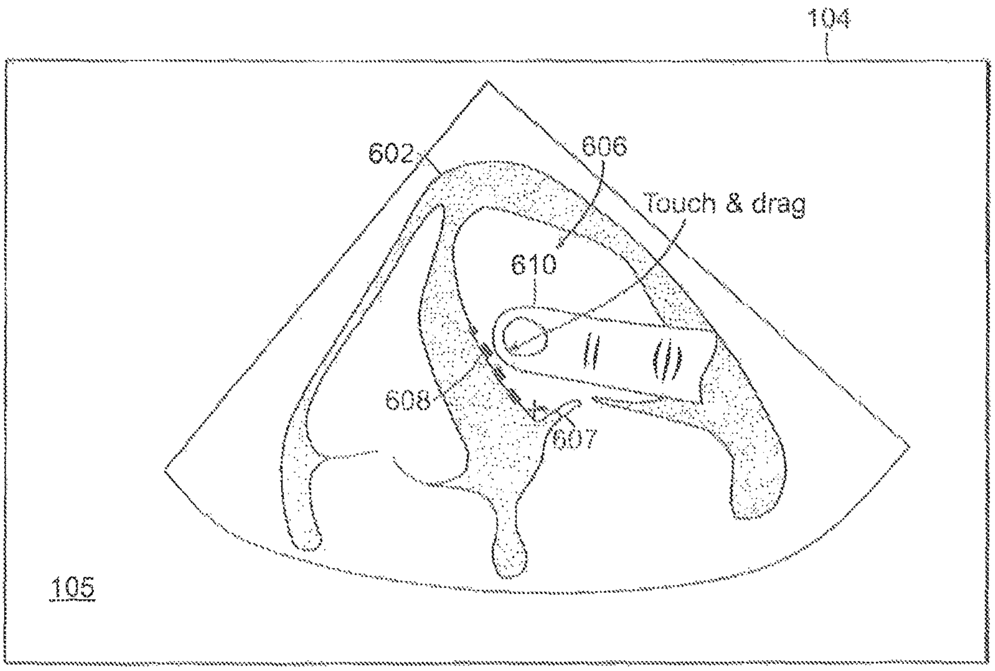

104
602
606
Touch & drag
610
608
607
105

FIG. 6C

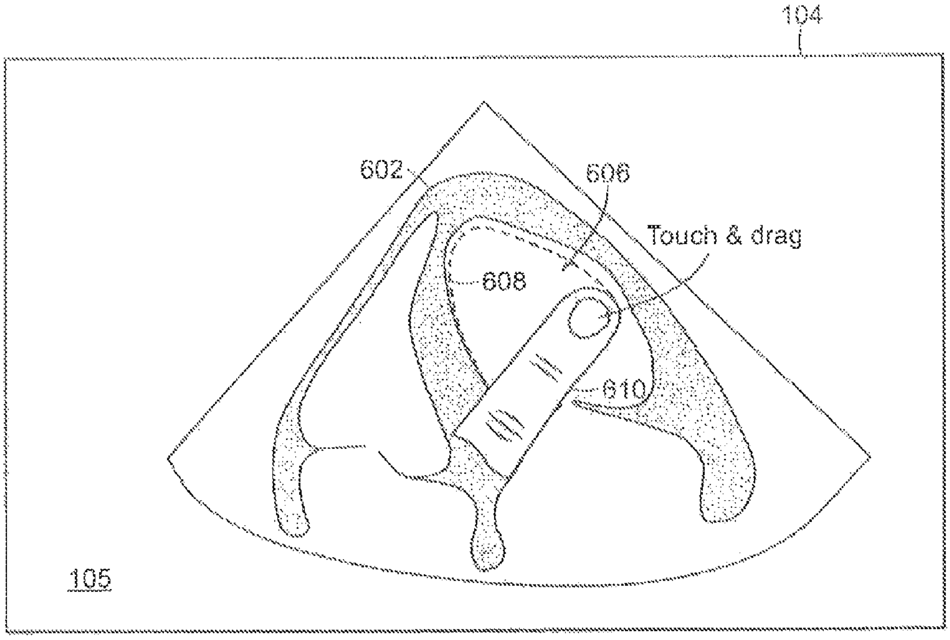

104
602
606
Touch & drag
608
610
105

FIG. 6D

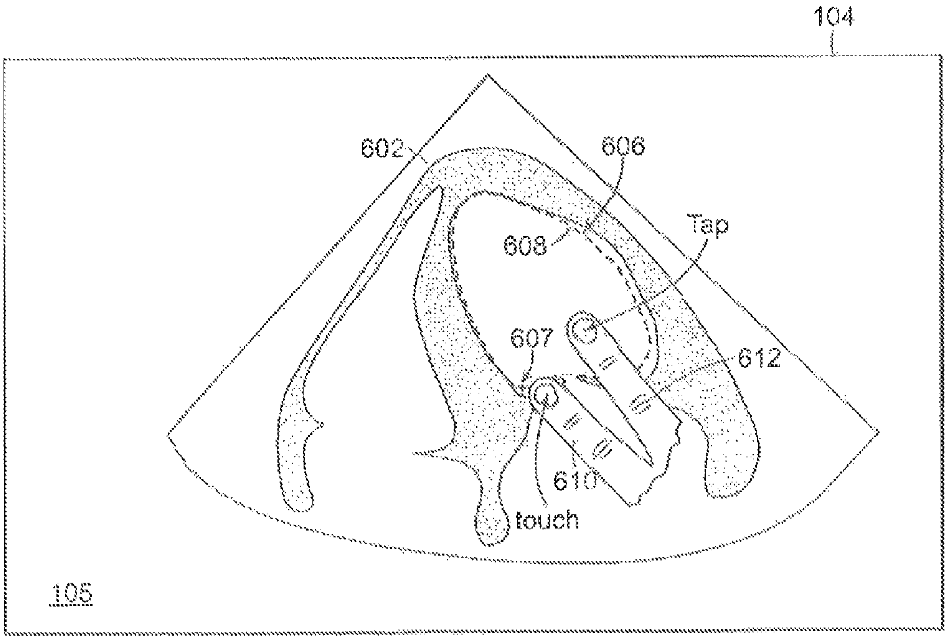

104
602
606
Tap
608
607
612
610
touch
105

FIG. 6E

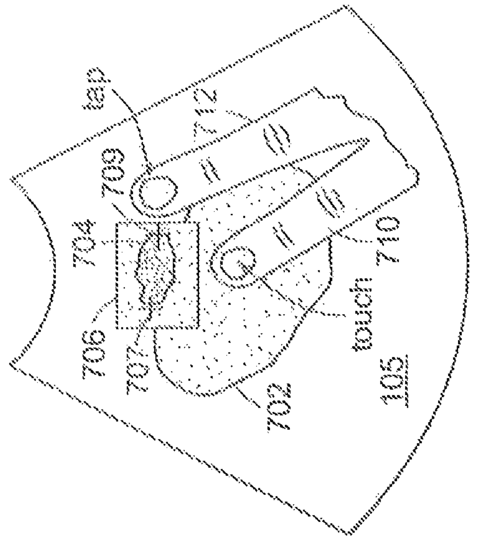


FIG. 7C

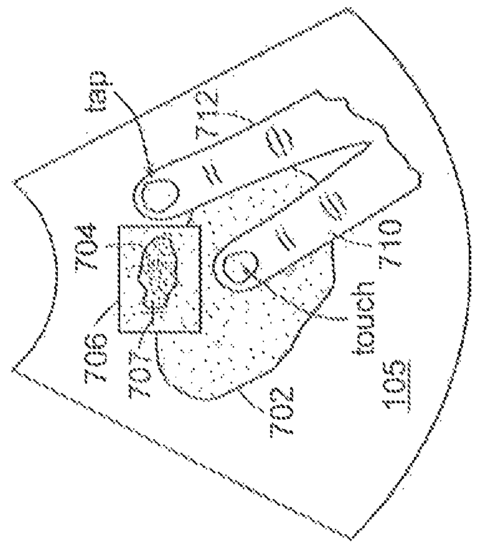


FIG. 7B

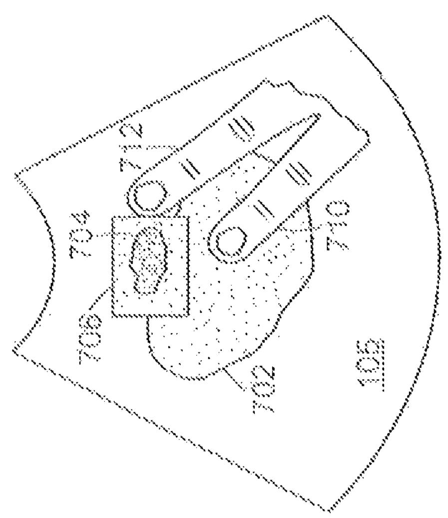


FIG. 7A

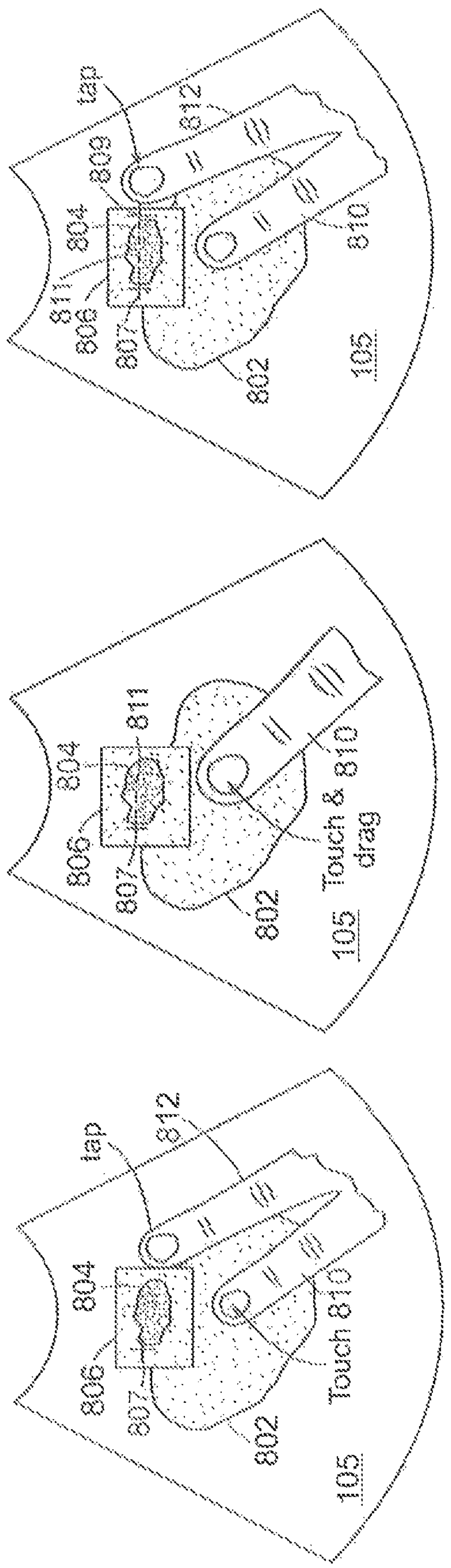


FIG. 8C

FIG. 8B

FIG. 8A

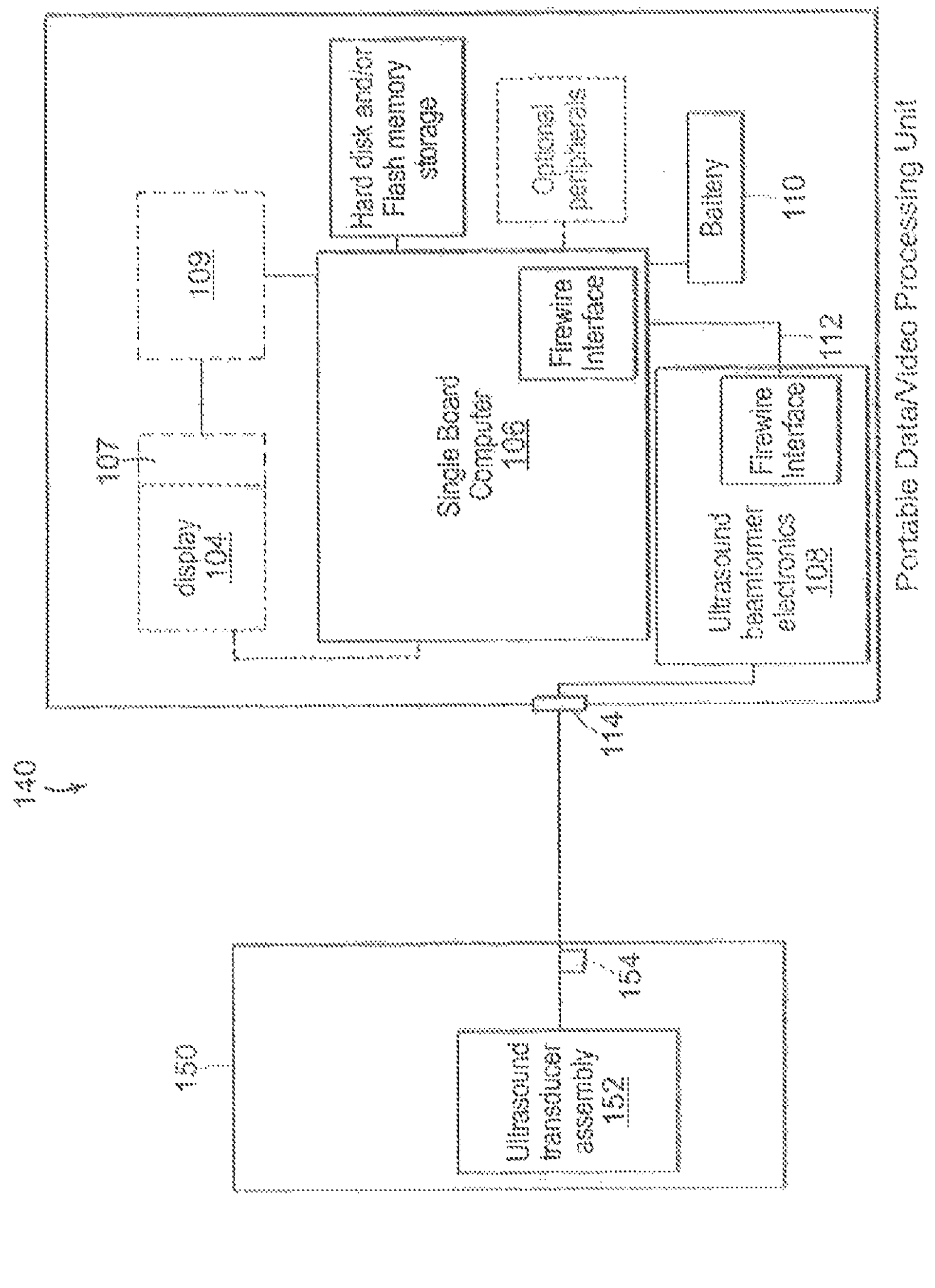

Hard disk and/or Flash memory storage
Optional peripherals
Battery
110
109
Firewire Interface
112
Single Board Computer 106
107
display 104
Firewire Interface
Ultrasound beamformer electronics 108
Portable Data/Video Processing Unit
114
140
150
154
Ultrasound transducer assembly 152

FIG. 9A

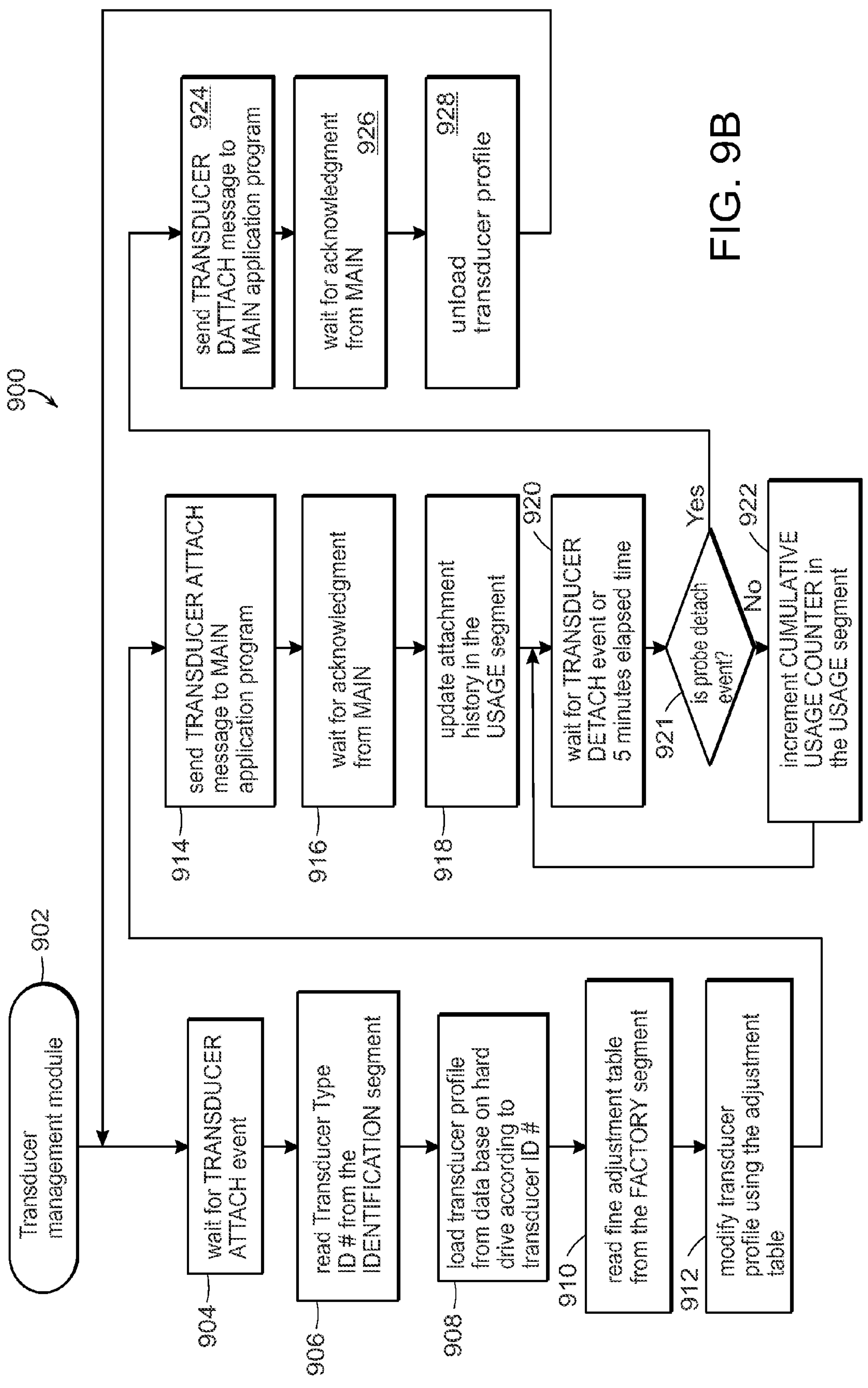

900
Transducer management module
902
wait for TRANSDUCER ATTACH event
904
read Transducer Type ID # from the IDENTIFICATION segment
906
load transducer profile from data base on hard drive according to transducer ID #
908
read fine adjustment table from the FACTORY segment
910
modify transducer profile using the adjustment table
912
send TRANSDUCER ATTACH message to MAIN application program
914
wait for acknowledgment from MAIN
916
update attachment history in the USAGE segment
918
wait for TRANSDUCER DETACH event or 5 minutes elapsed time
920
is probe detach event?
921
Yes
No
increment CUMULATIVE USAGE COUNTER in the USAGE segment
922
send TRANSDUCER DATTACH message to MAIN application program
924
wait for acknowledgment from MAIN
926
unload transducer profile
928

FIG. 9B

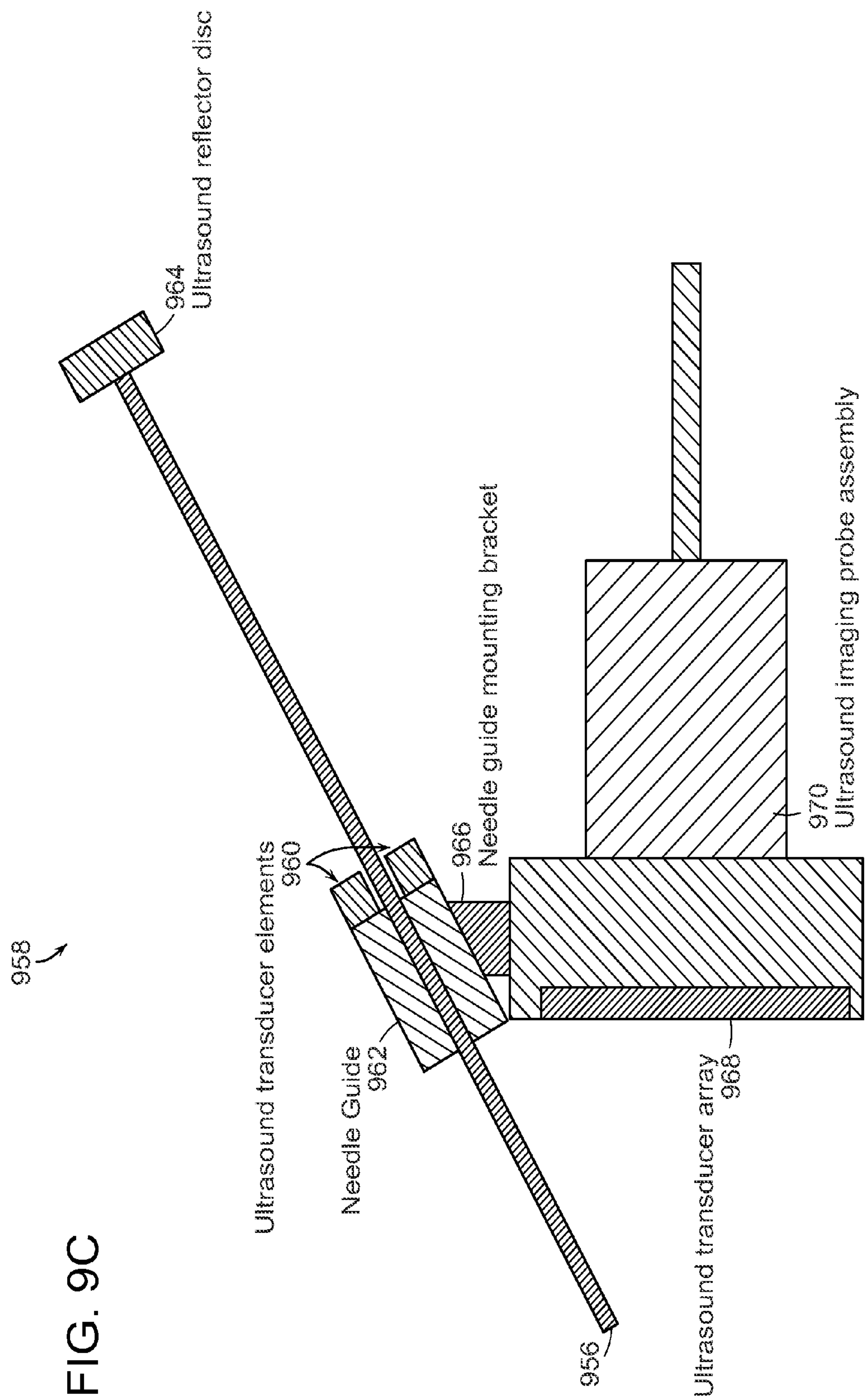

958
964
Ultrasound reflector disc
Ultrasound transducer elements
960
Needle Guide
962
966
Needle guide mounting bracket
970
Ultrasound imaging probe assembly
Ultrasound transducer array
968
956

FIG. 9C

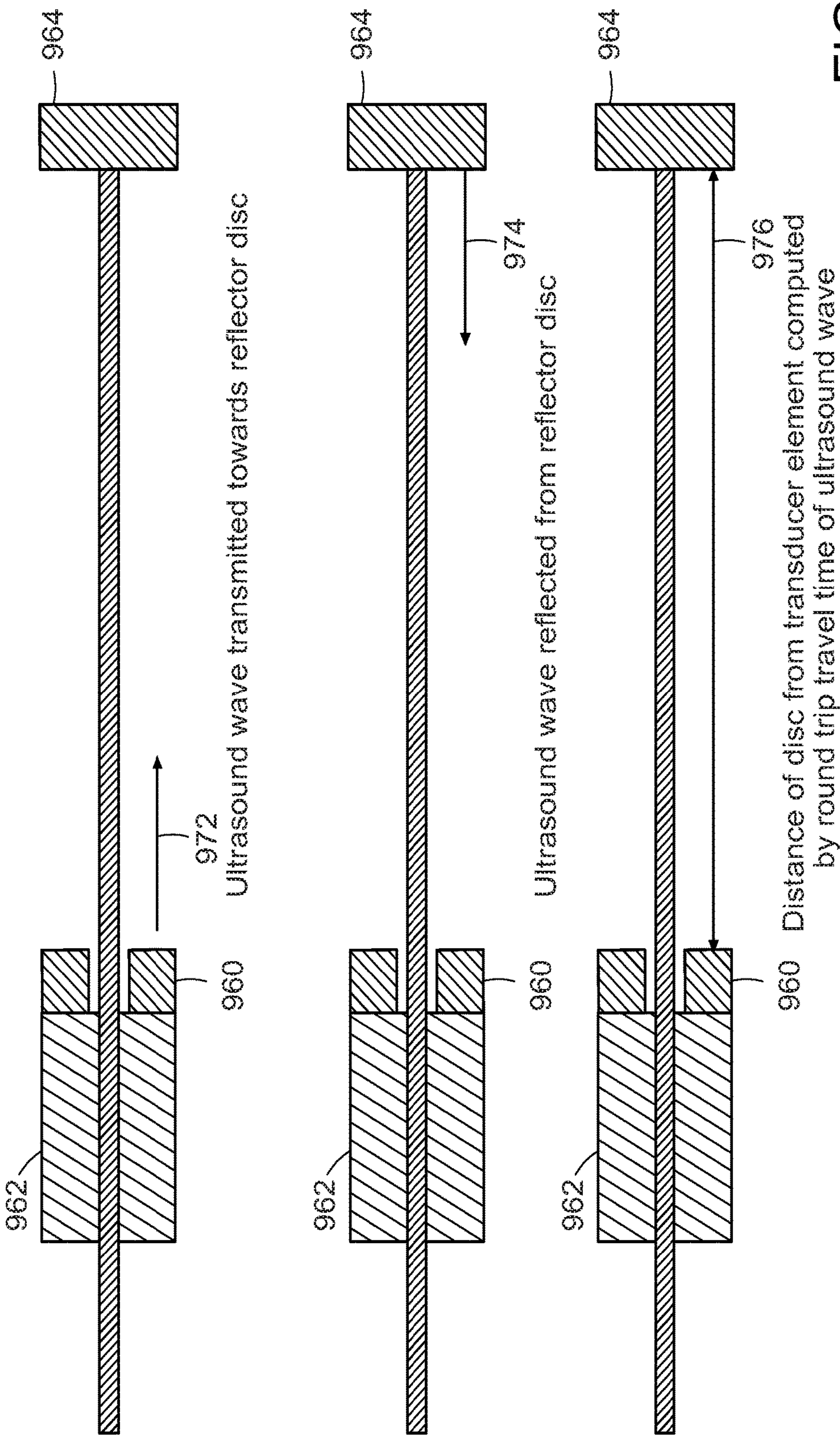
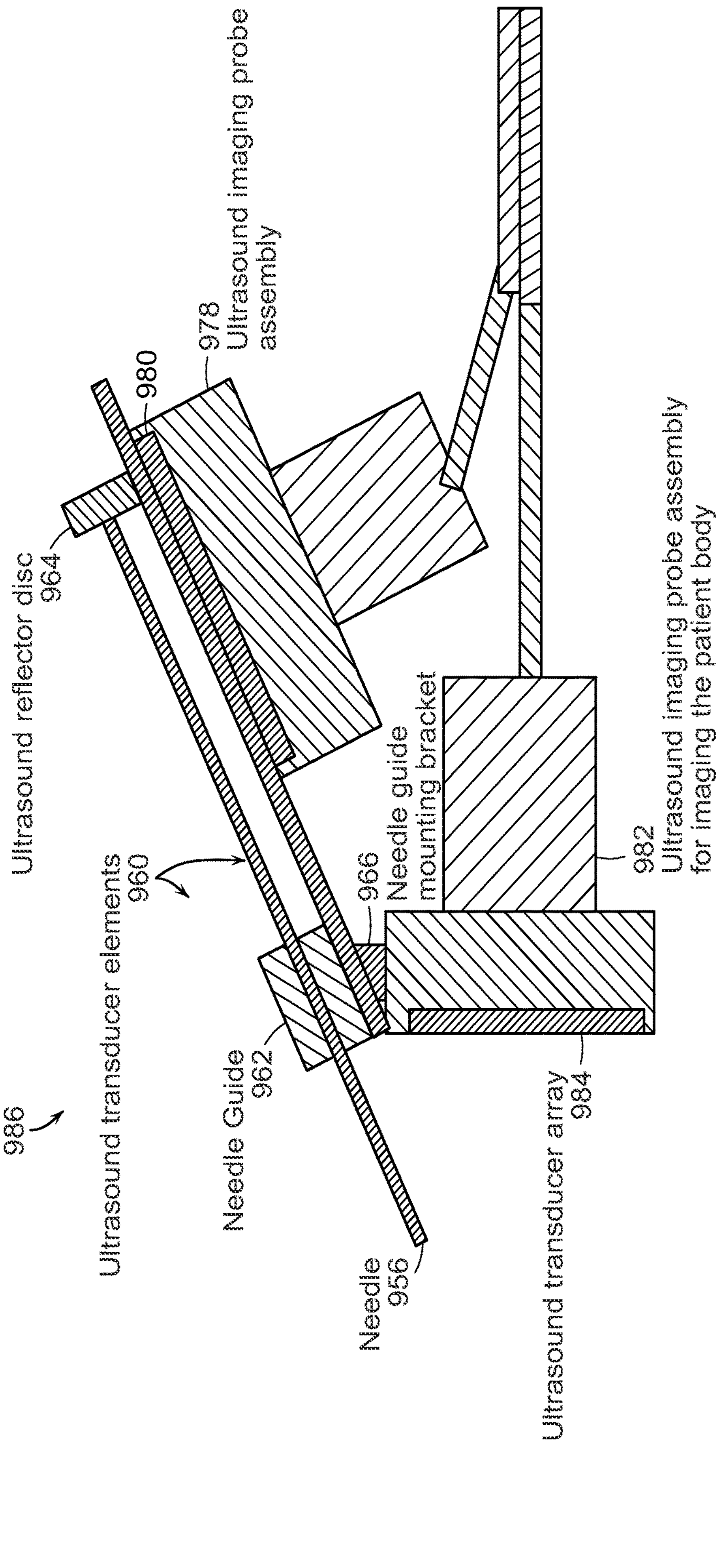
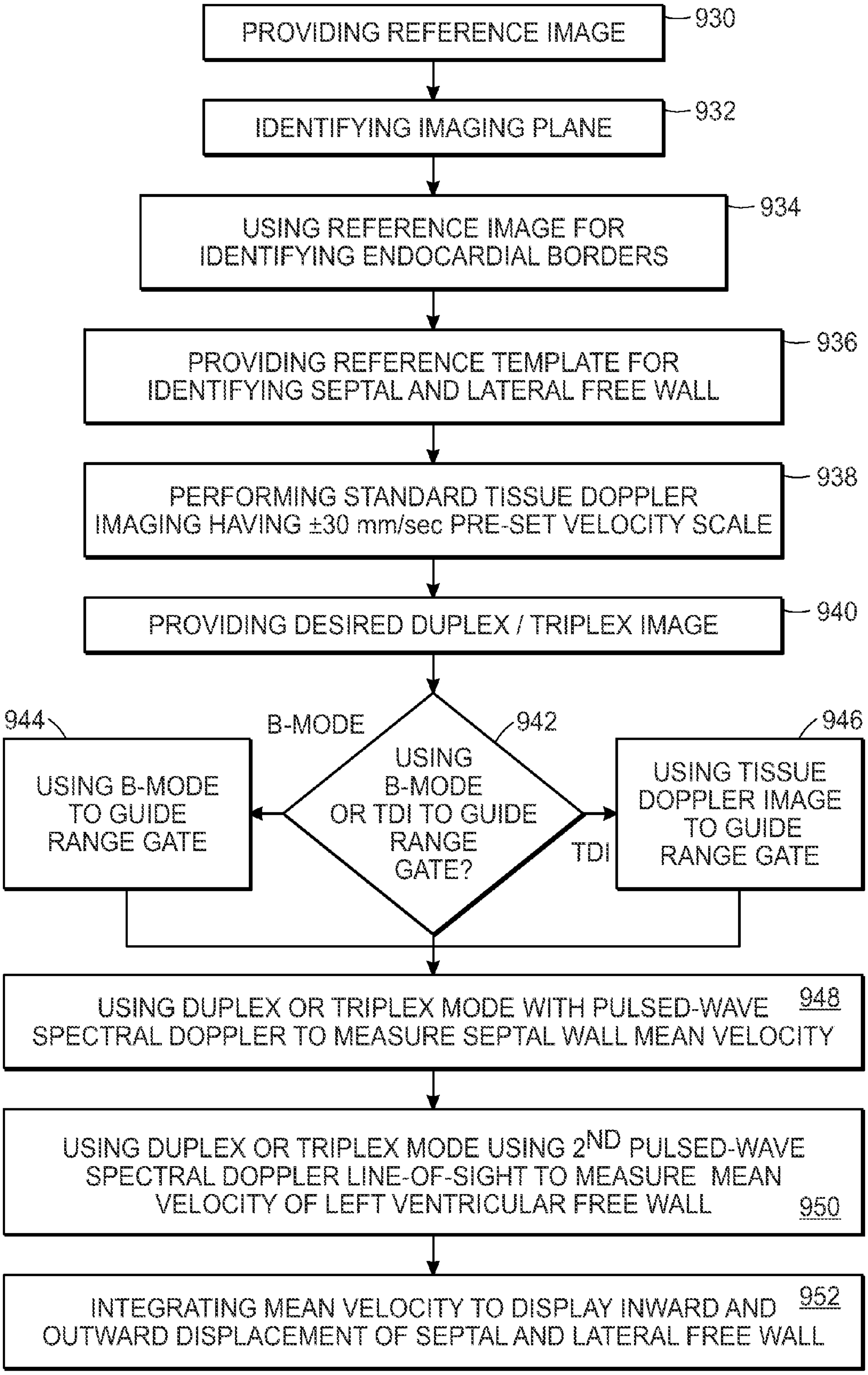

964
964
964
972
Ultrasound wave transmitted towards reflector disc
974
Ultrasound wave reflected from reflector disc
976
Distance of disc from transducer element computed
by round trip travel time of ultrasound wave
960
960
960
962
962
962

FIG. 9D



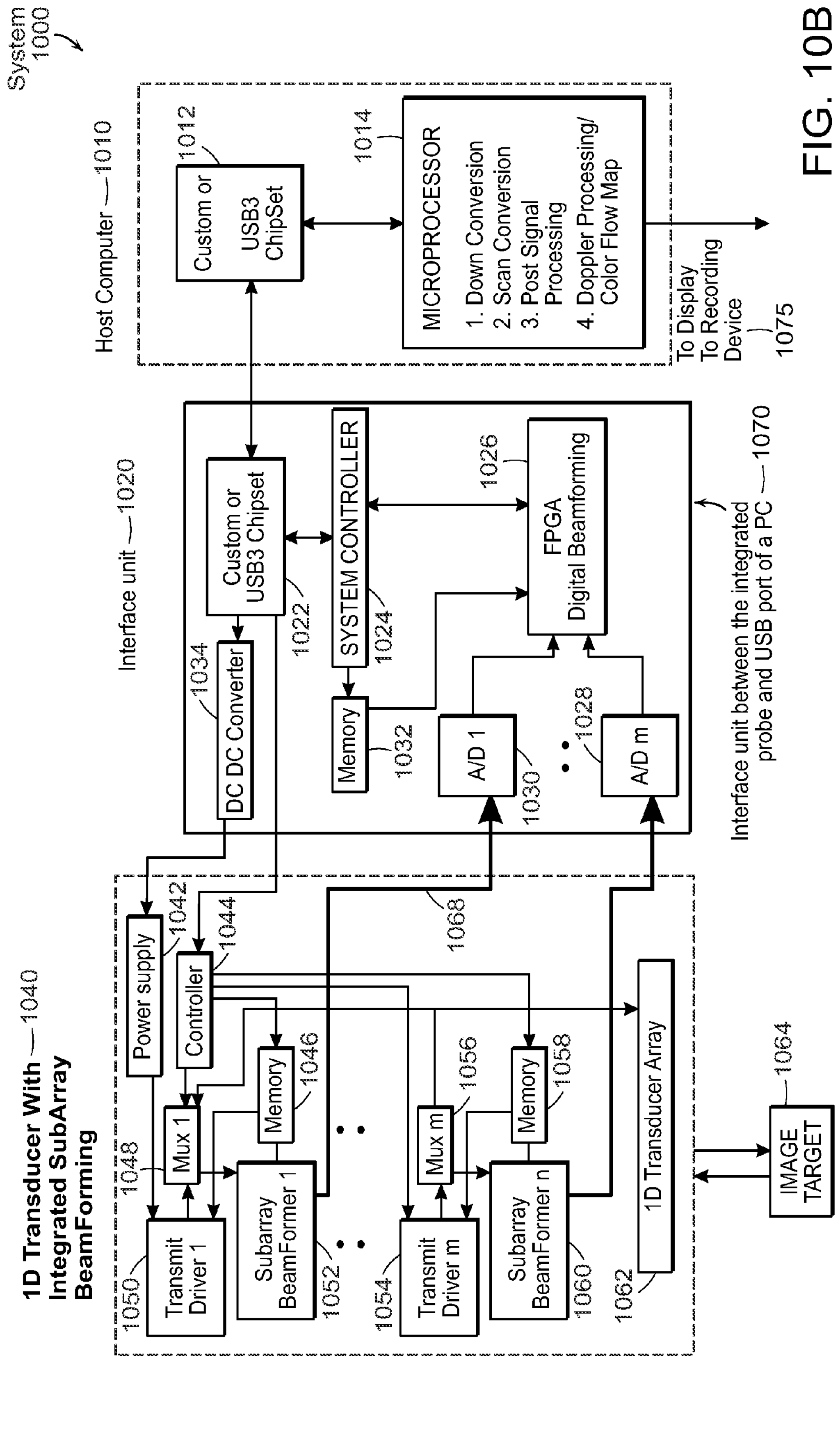
978
Ultrasound imaging probe assembly
980
Ultrasound reflector disc
964
Ultrasound transducer elements
960
966
Needle guide mounting bracket
982
Ultrasound imaging probe assembly for imaging the patient body
986
Needle Guide
962
Needle
956
Ultrasound transducer array
984

FIG. 9E



PROVIDING REFERENCE IMAGE
930
IDENTIFYING IMAGING PLANE
932
USING REFERENCE IMAGE FOR IDENTIFYING ENDOCARDIAL BORDERS
934
PROVIDING REFERENCE TEMPLATE FOR IDENTIFYING SEPTAL AND LATERAL FREE WALL
936
PERFORMING STANDARD TISSUE DOPPLER IMAGING HAVING ±30 mm/sec PRE-SET VELOCITY SCALE
938
PROVIDING DESIRED DUPLEX / TRIPLEX IMAGE
940
944
B-MODE
942
946
USING B-MODE TO GUIDE RANGE GATE
USING B-MODE OR TDI TO GUIDE RANGE GATE?
TDI
USING TISSUE DOPPLER IMAGE TO GUIDE RANGE GATE
USING DUPLEX OR TRIPLEX MODE WITH PULSED-WAVE SPECTRAL DOPPLER TO MEASURE SEPTAL WALL MEAN VELOCITY
948
USING DUPLEX OR TRIPLEX MODE USING 2ND PULSED-WAVE SPECTRAL DOPPLER LINE-OF-SIGHT TO MEASURE MEAN VELOCITY OF LEFT VENTRICULAR FREE WALL
950
INTEGRATING MEAN VELOCITY TO DISPLAY INWARD AND OUTWARD DISPLACEMENT OF SEPTAL AND LATERAL FREE WALL
952

FIG. 10A



System 1000
Host Computer 1010
Custom or USB3 ChipSet
1012
1014
MICROPROCESSOR
1. Down Conversion
2. Scan Conversion
3. Post Signal Processing
4. Doppler Processing/ Color Flow Map
To Display To Recording Device
1075
Interface unit 1020
Custom or USB3 Chipset
1022
SYSTEM CONTROLLER
1024
1026
FPGA Digital Beamforming
1034
DC DC Converter
Memory
1032
A/D 1
1030
1028
A/D m
Interface unit between the integrated probe and USB port of a PC 1070
1D Transducer With Integrated SubArray BeamForming 1040
Power supply
1042
Controller
1044
1068
Memory
1046
Mux 1
1048
Transmit Driver 1
1050
Subarray BeamFormer 1
1052
Transmit Driver m
1054
Mux m
1056
Memory
1058
Subarray BeamFormer n
1060
1D Transducer Array
1062
IMAGE TARGET
1064

FIG. 10B

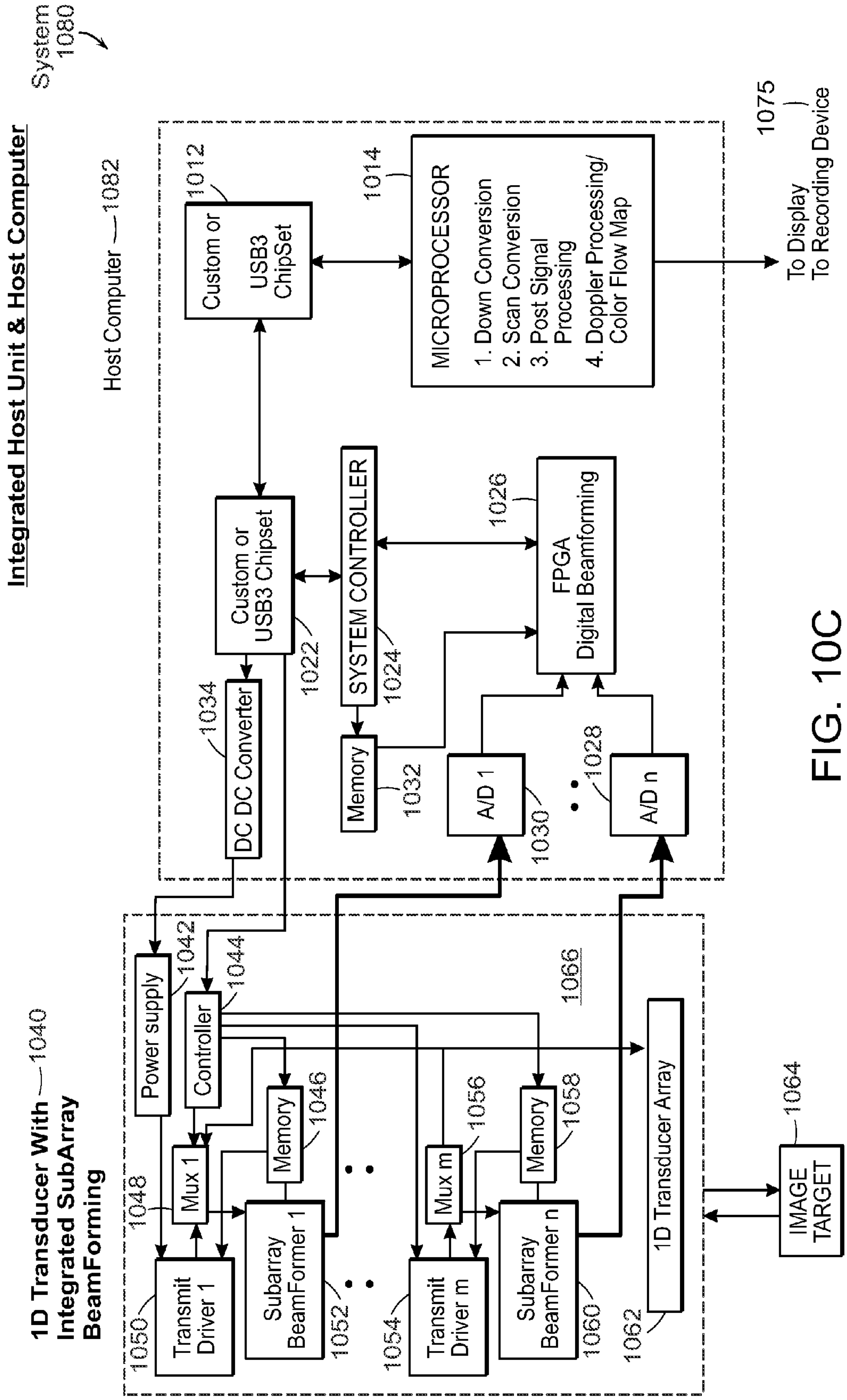

Integrated Host Unit & Host Computer
System 1080
Host Computer 1082
Custom or USB3 ChipSet
1012
1014
MICROPROCESSOR
1. Down Conversion
2. Scan Conversion
3. Post Signal Processing
4. Doppler Processing/ Color Flow Map
1075
To Display
To Recording Device
Custom or USB3 Chipset
1022
SYSTEM CONTROLLER
1024
1026
FPGA
Digital Beamforming
DC DC Converter
1034
Memory
1032
A/D 1
1030
A/D n
1028
1D Transducer With Integrated SubArray BeamForming
1040
Power supply
1042
Controller
1044
1066
Memory
1046
Mux 1
1048
Transmit Driver 1
1050
Subarray BeamFormer 1
1052
Mux m
1056
Memory
1058
Transmit Driver m
1054
Subarray BeamFormer n
1060
1D Transducer Array
1062
IMAGE TARGET
1064

FIG. 10C

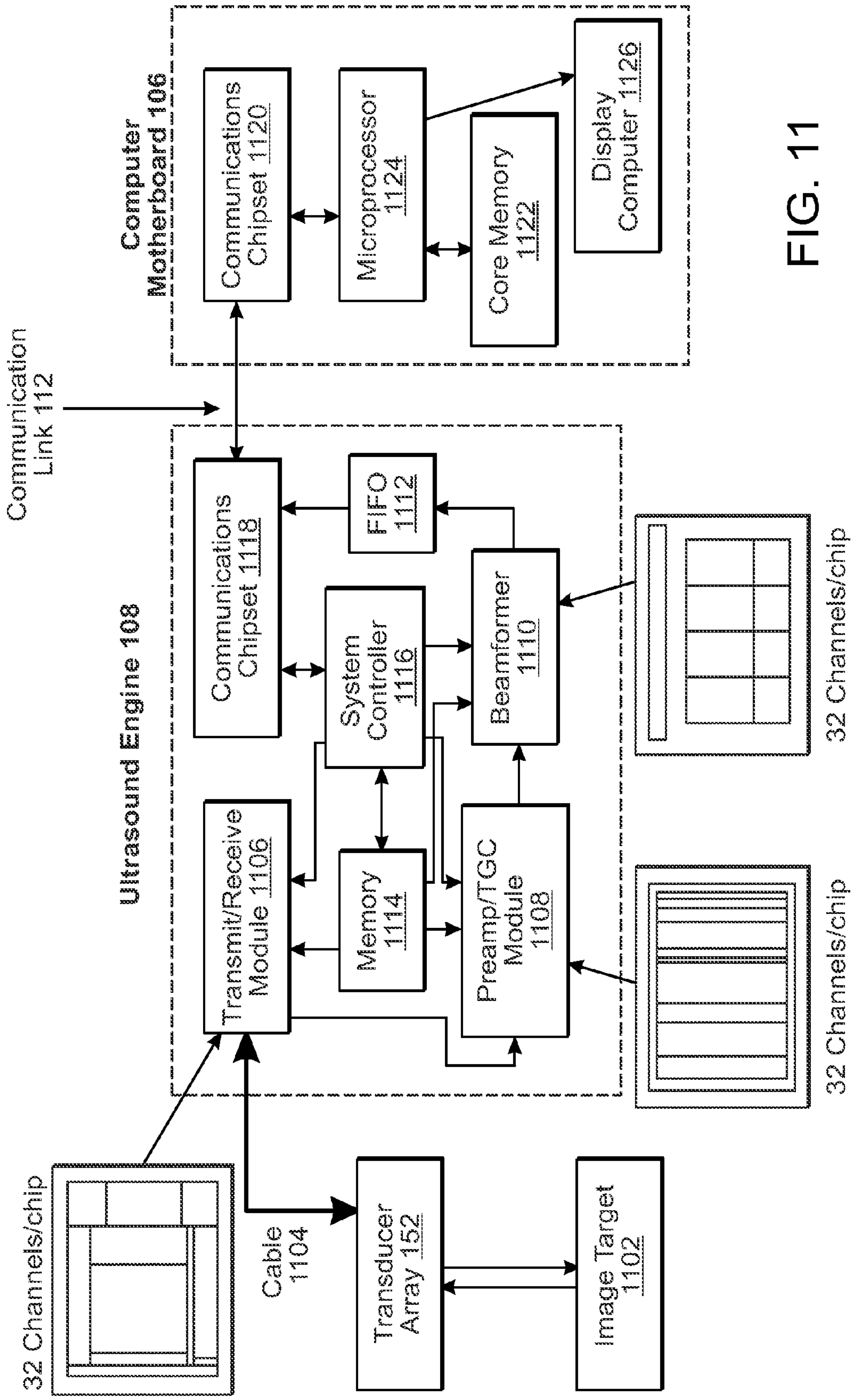

Computer Motherboard 106
Communications Chipset 1120
Microprocessor 1124
Core Memory 1122
Display Computer 1126
Communication Link 112
Ultrasound Engine 108
Communications Chipset 1118
FIFO 1112
System Controller 1116
Beamformer 1110
Transmit/Receive Module 1106
Memory 1114
Preamp/TGC Module 1108
32 Channels/chip
32 Channels/chip
32 Channels/chip
Cable 1104
Transducer Array 152
Image Target 1102

FIG. 11

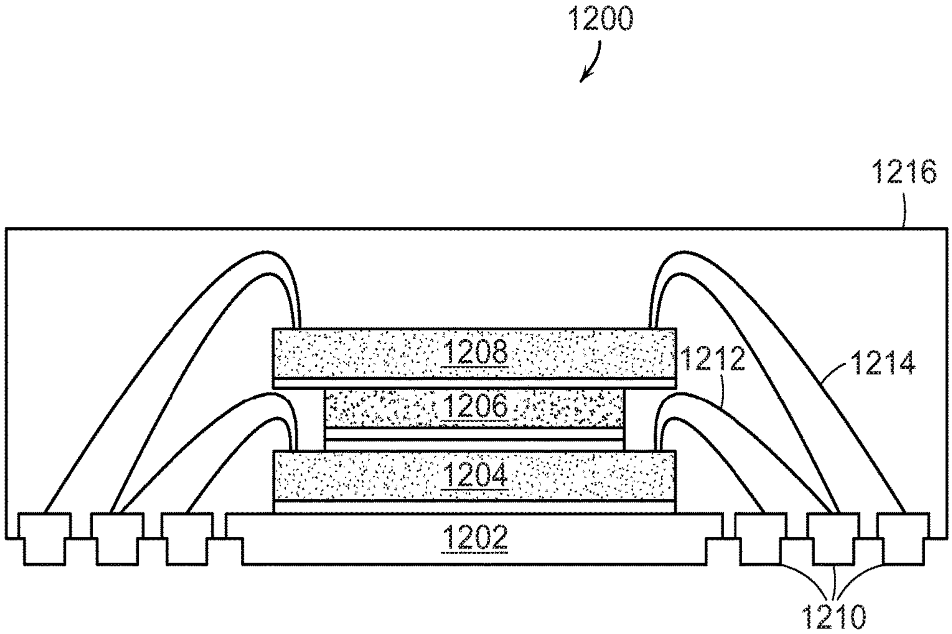


FIG. 12

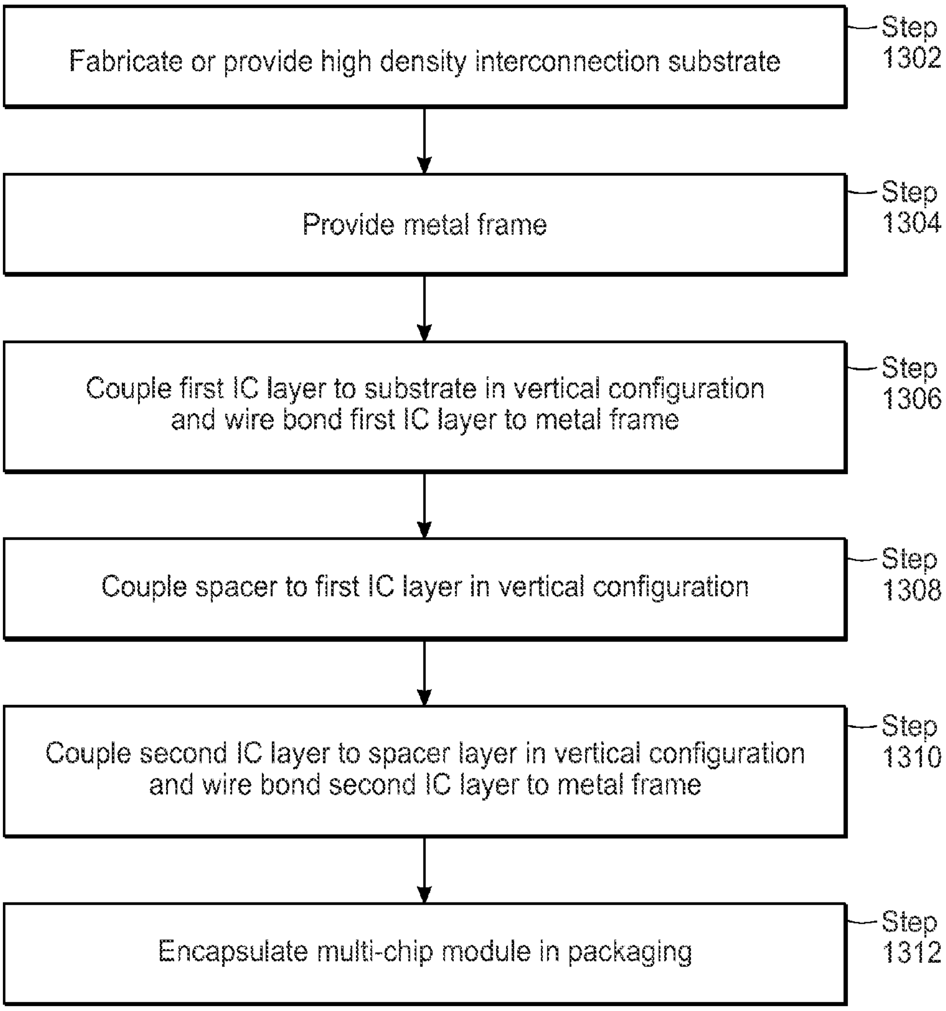

Fabricate or provide high density interconnection substrate
Step 1302
Provide metal frame
Step 1304
Couple first IC layer to substrate in vertical configuration and wire bond first IC layer to metal frame
Step 1306
Couple spacer to first IC layer in vertical configuration
Step 1308
Couple second IC layer to spacer layer in vertical configuration and wire bond second IC layer to metal frame
Step 1310
Encapsulate multi-chip module in packaging
Step 1312

FIG. 13

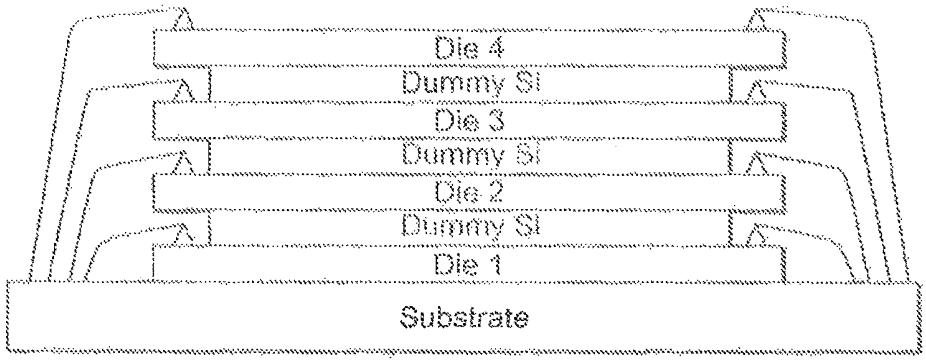


FIG. 14A

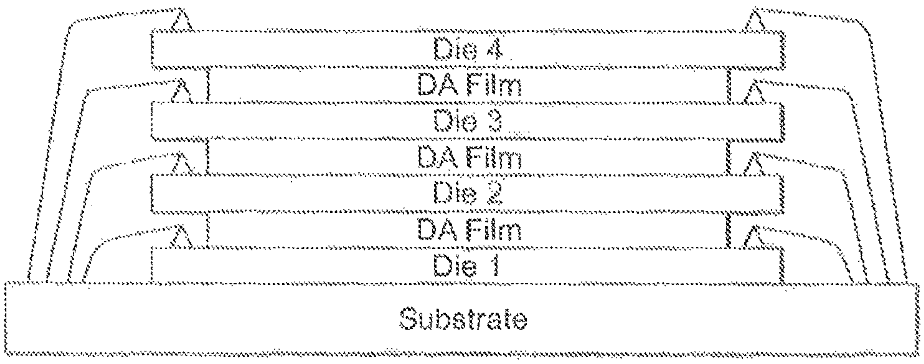


FIG. 14B

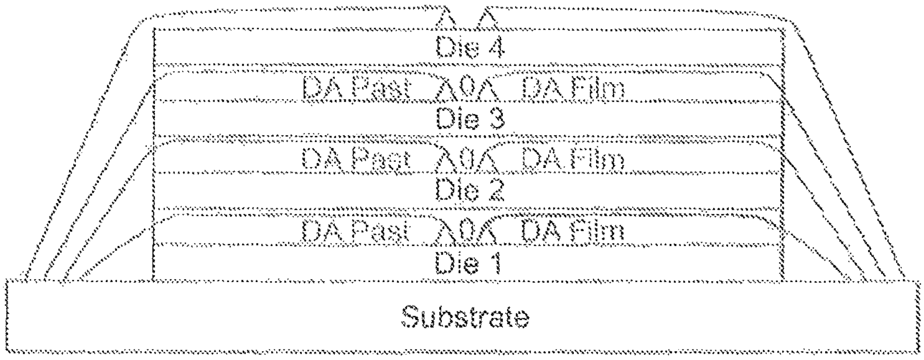


FIG. 14C

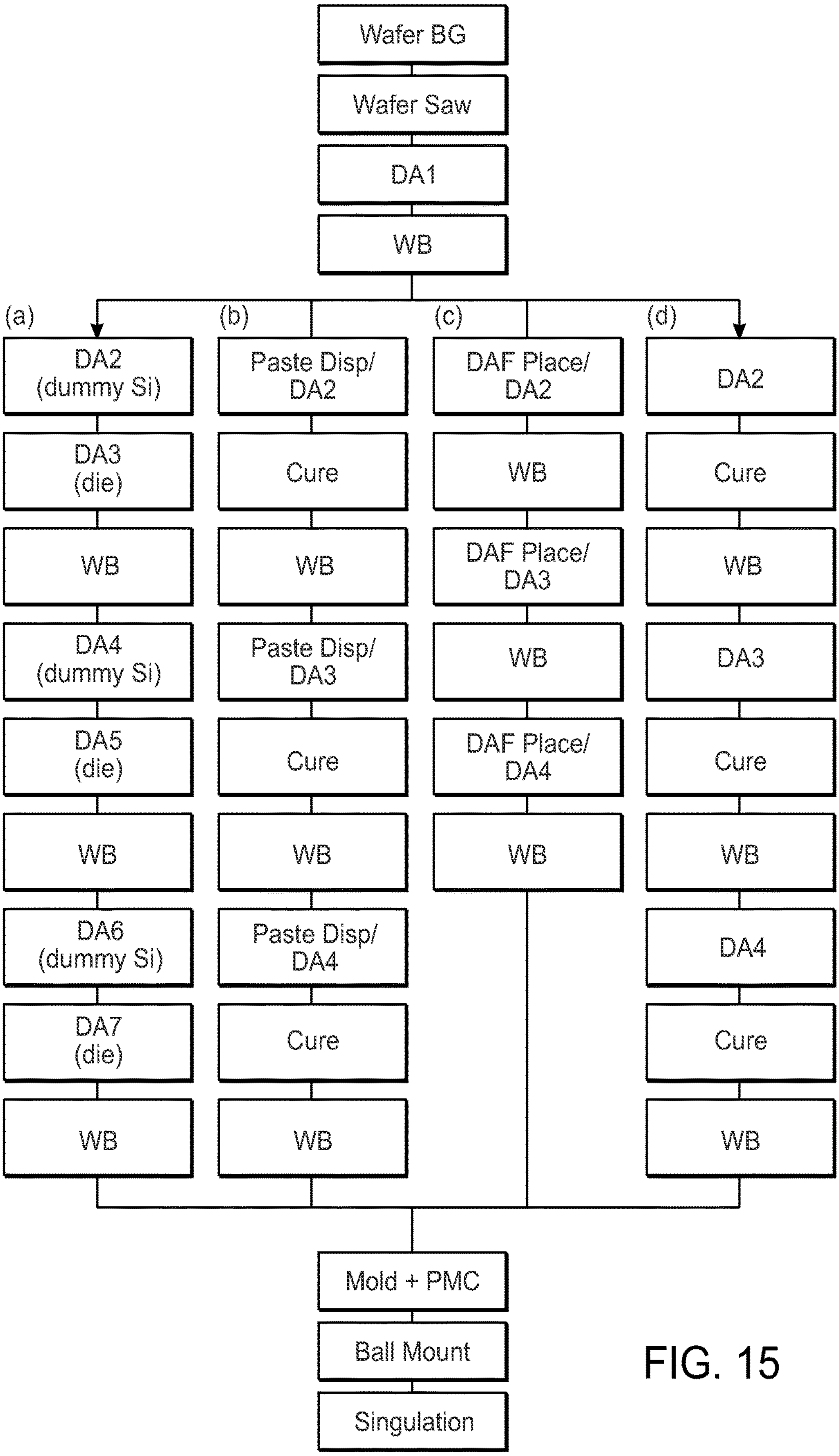

Wafer BG
Wafer Saw
DA1
WB
(a)
(b)
(c)
(d)
DA2 (dummy Si)
DA3 (die)
WB
DA4 (dummy Si)
DA5 (die)
WB
DA6 (dummy Si)
DA7 (die)
WB
Paste Disp/ DA2
Cure
WB
Paste Disp/ DA3
Cure
WB
Paste Disp/ DA4
Cure
WB
DAF Place/ DA2
WB
DAF Place/ DA3
WB
DAF Place/ DA4
WB
DA2
Cure
WB
DA3
Cure
WB
DA4
Cure
WB
Mold + PMC
Ball Mount
Singulation

FIG. 15

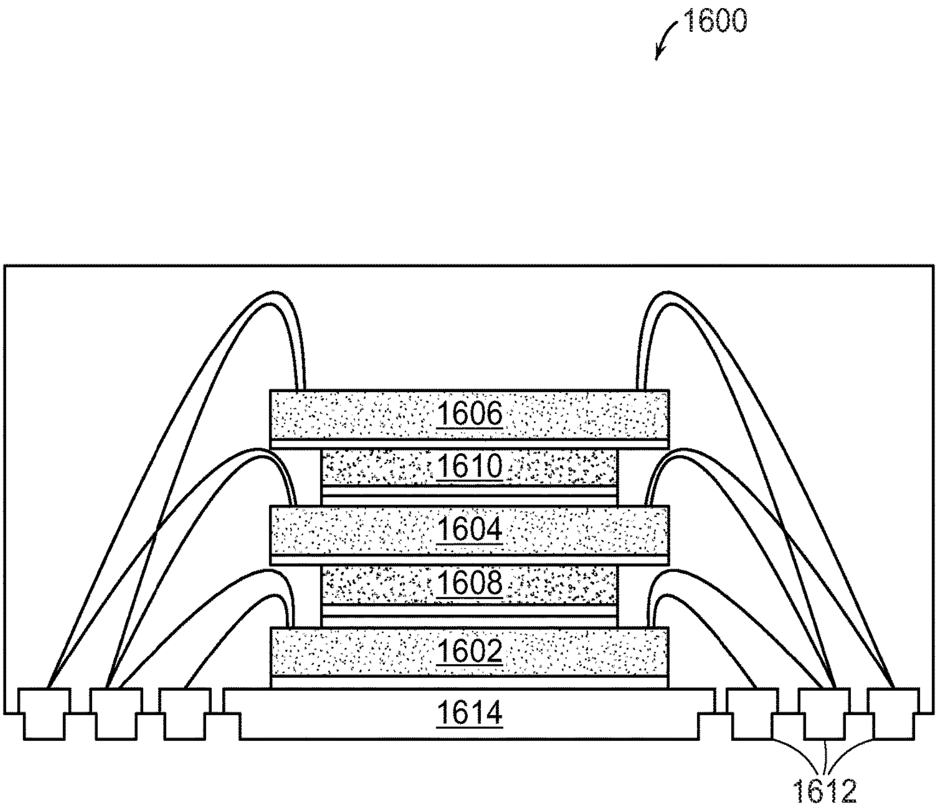


FIG. 16

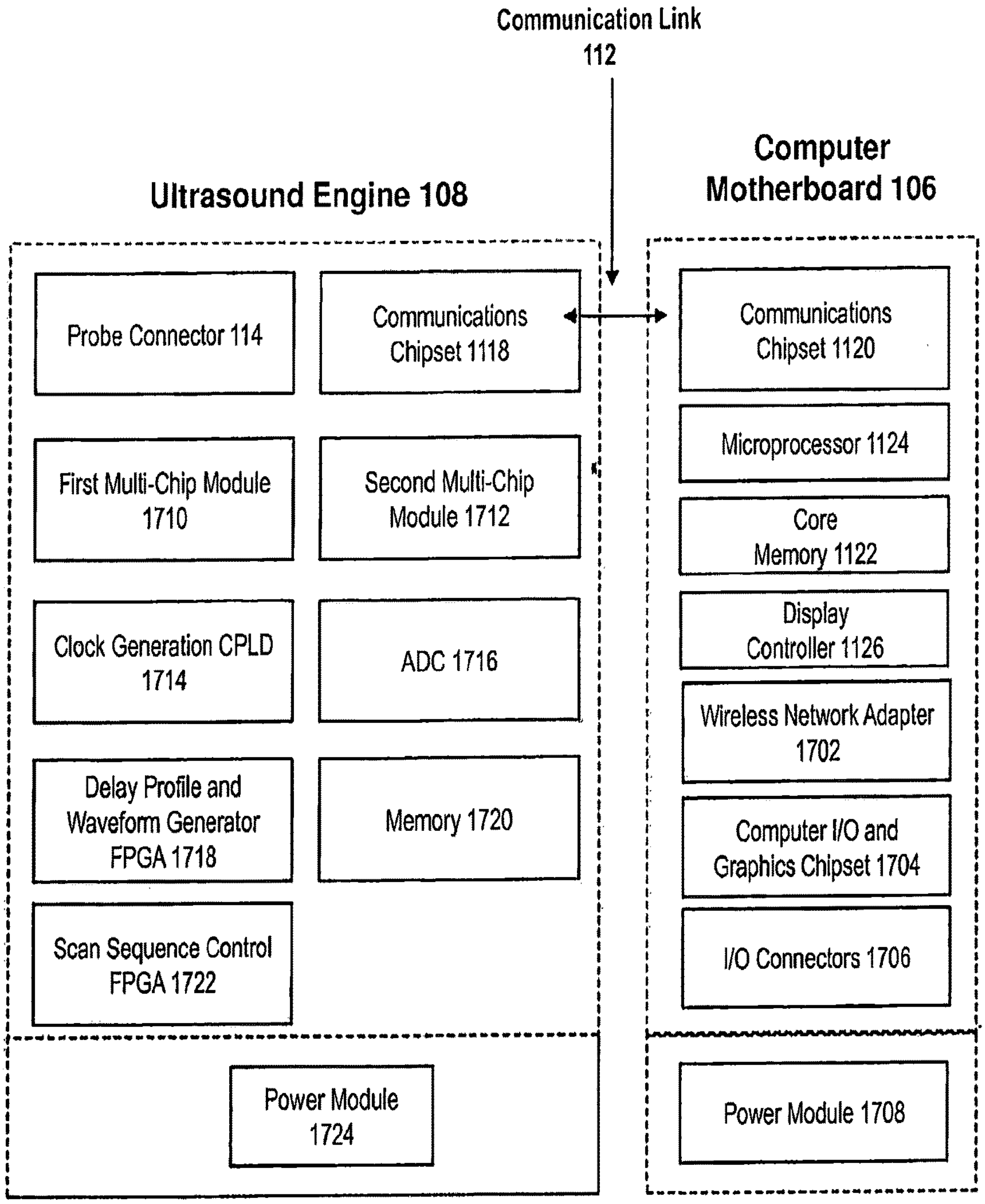

Communication Link
112
Computer
Motherboard 106
Ultrasound Engine 108
Probe Connector 114
Communications
Chipset 1118
Communications
Chipset 1120
Microprocessor 1124
First Multi-Chip Module
1710
Second Multi-Chip
Module 1712
Core
Memory 1122
Display
Controller 1126
Clock Generation CPLD
1714
ADC 1716
Wireless Network Adapter
1702
Delay Profile and
Waveform Generator
FPGA 1718
Memory 1720
Computer I/O and
Graphics Chipset 1704
Scan Sequence Control
FPGA 1722
I/O Connectors 1706
Power Module
1724
Power Module 1708

FIG. 17

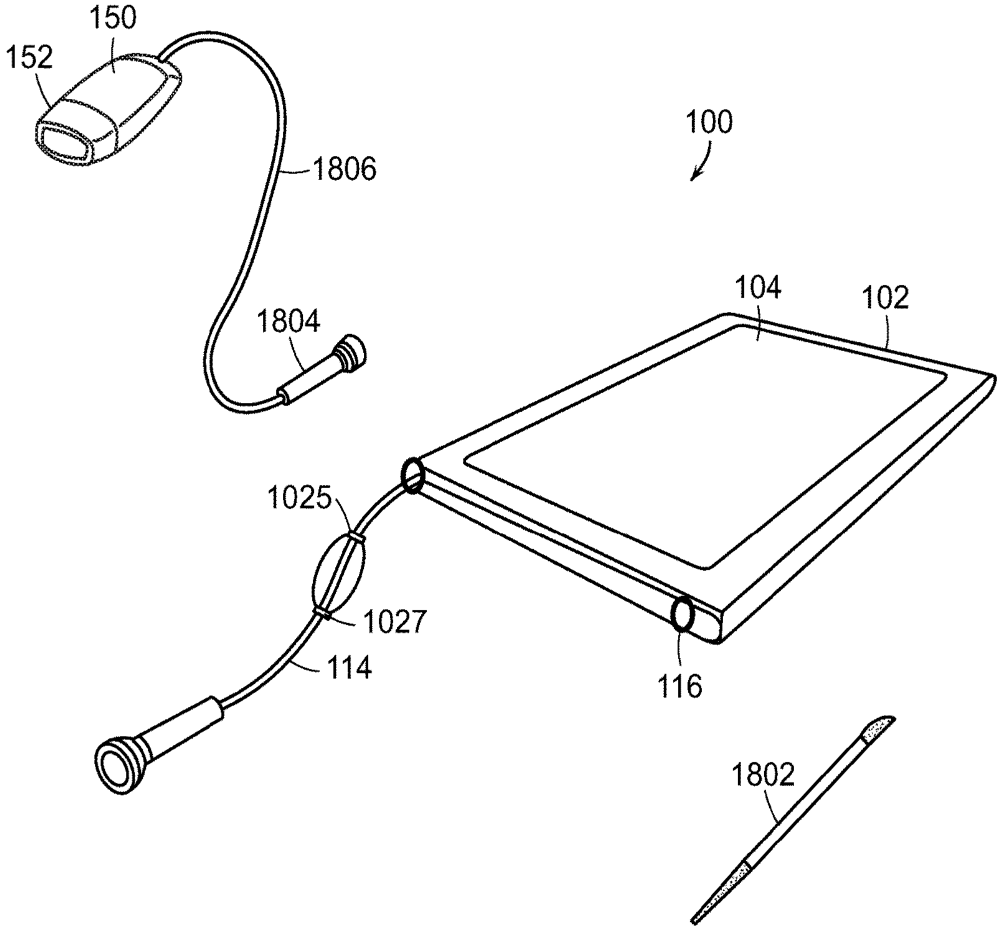


FIG. 18

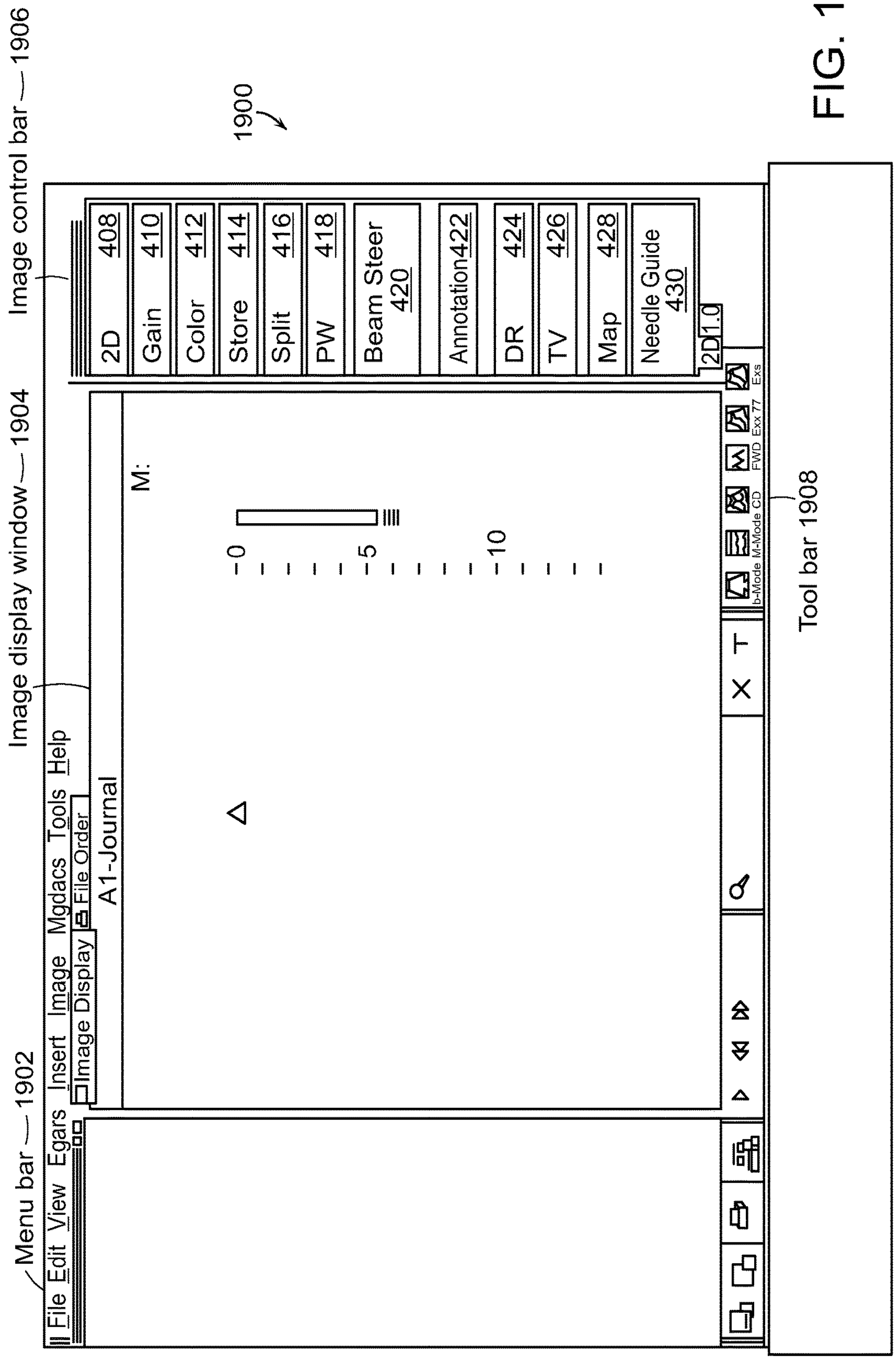


Image control bar 1906
Image display window 1904
Menu bar 1902
1900
File Edit View Egars Insert Image Mgdacs Tools Help
Image Display
File Order
A1-Journal
M:
0
5
10
2D 408
Gain 410
Color 412
Store 414
Split 416
PW 418
Beam Steer 420
Annotation422
DR 424
TV 426
Map 428
Needle Guide 430
2D1.0
b-Mode M-Mode CD FWD Exx 77 Exs
Tool bar 1908

FIG. 19

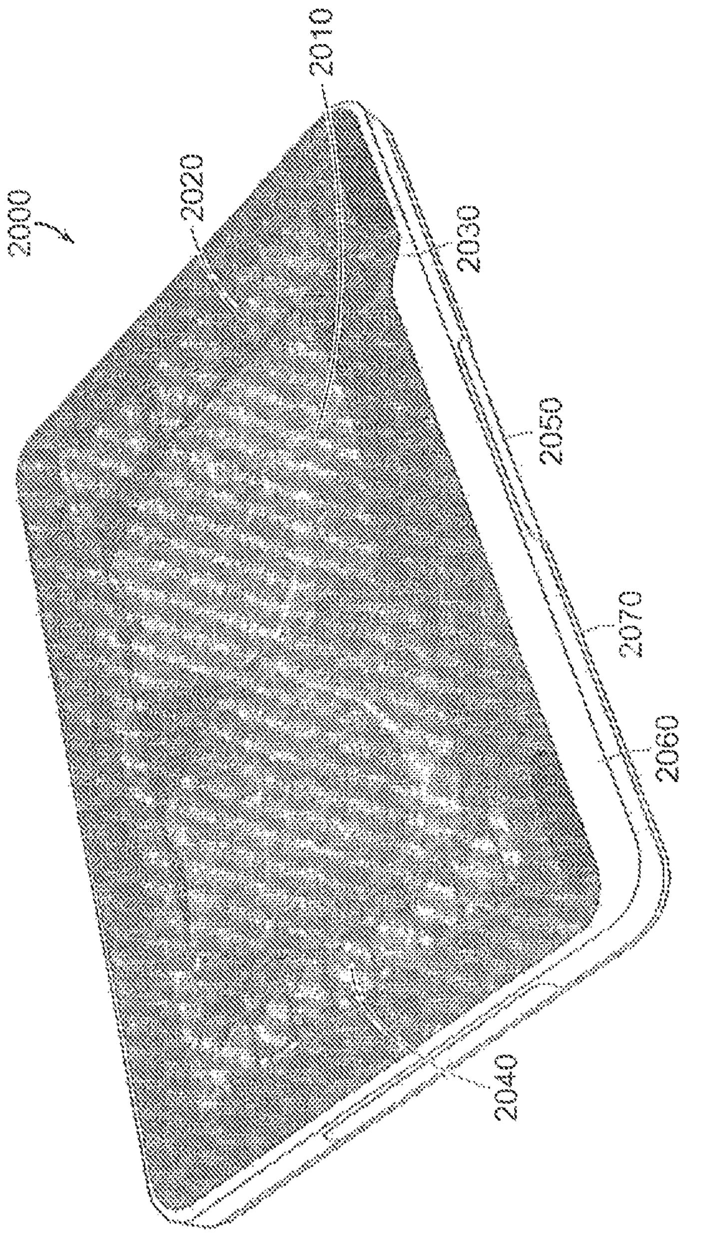


FIG. 20

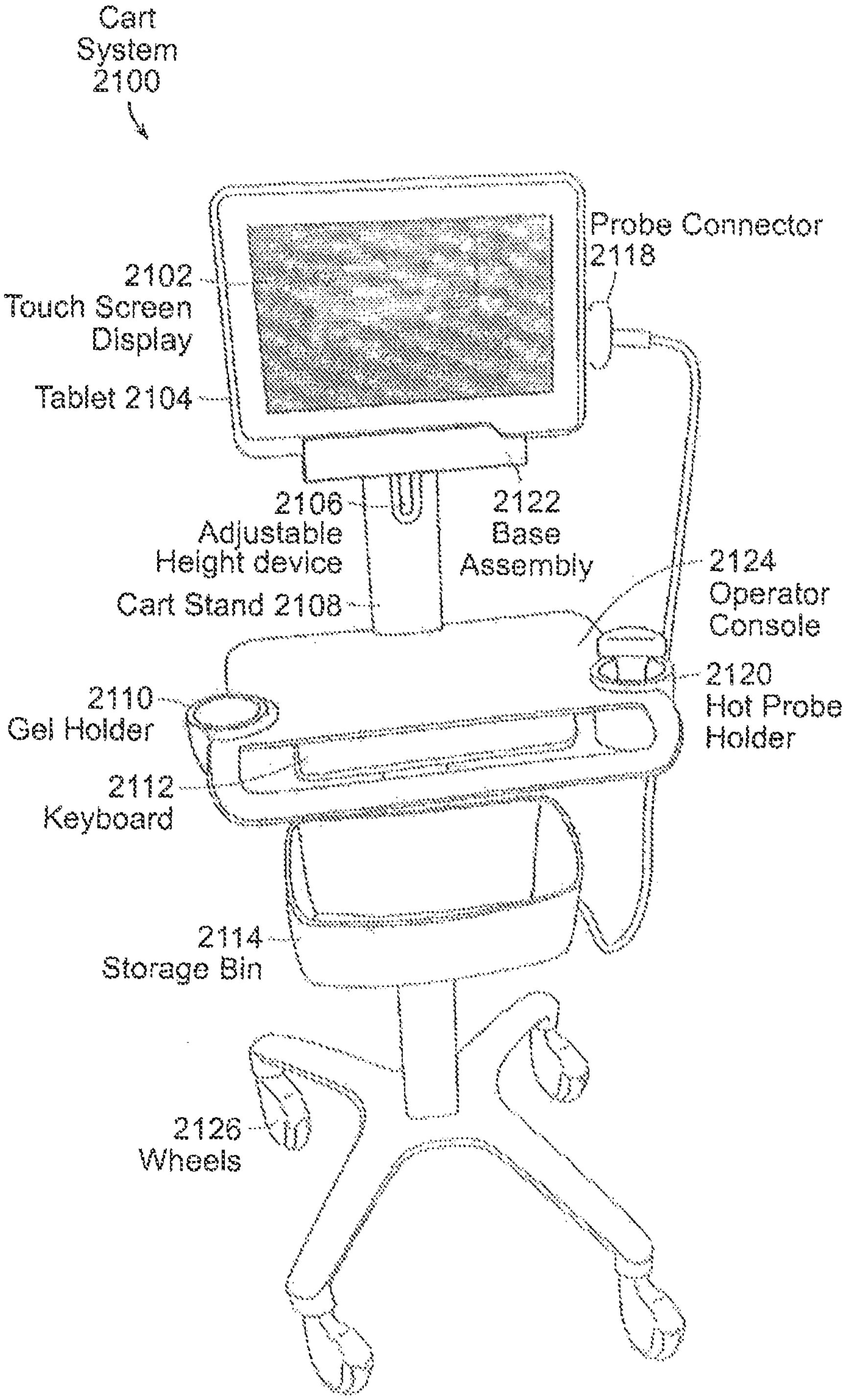

Cart
System
2100
Probe Connector
2118
2102
Touch Screen
Display
Tablet 2104
2106
Adjustable
Height device
2122
Base
Assembly
Cart Stand 2108
2124
Operator
Console
2120
Hot Probe
Holder
2110
Gel Holder
2112
Keyboard
2114
Storage Bin
2126
Wheels

FIG. 21

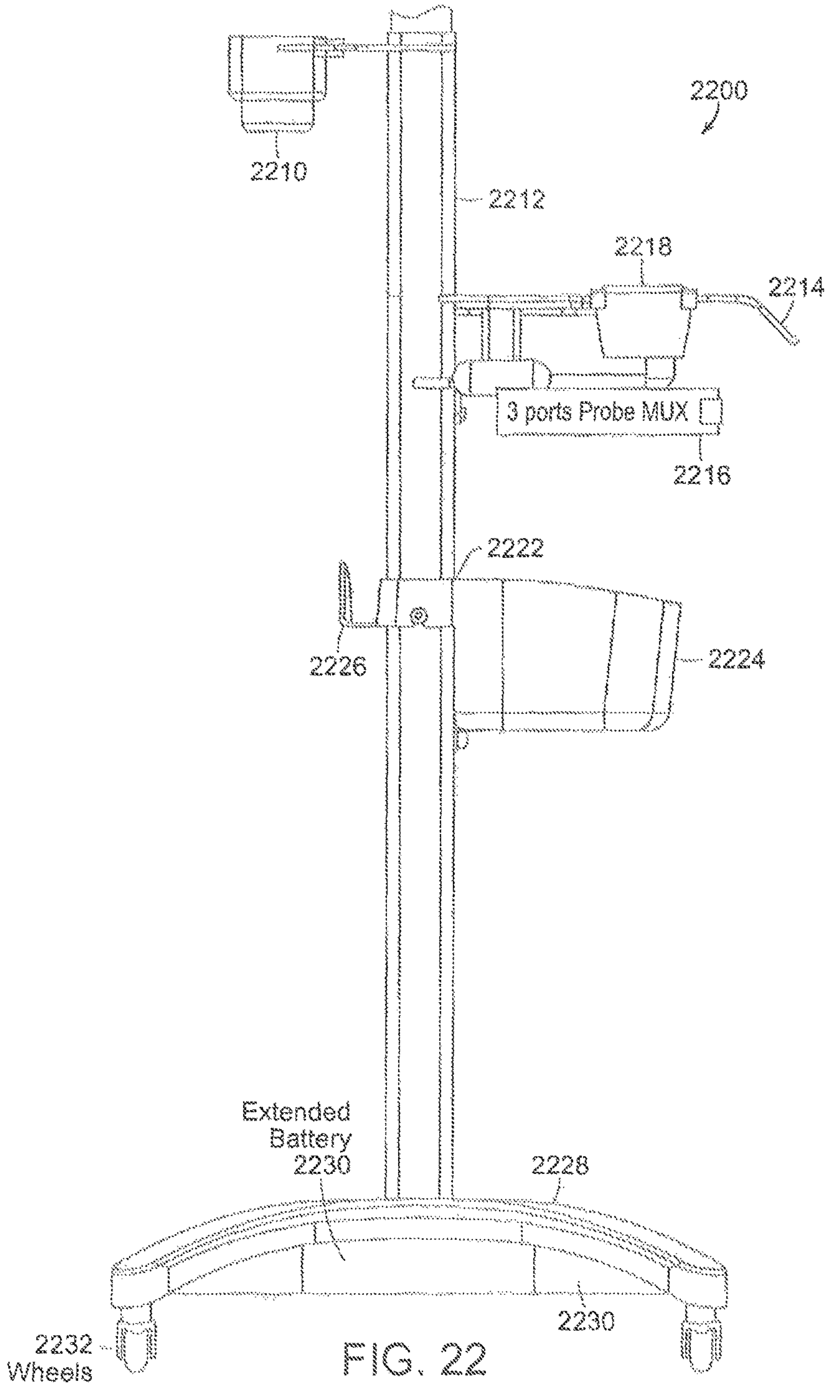

2200
2210
2212
2218
2214
3 ports Probe MUX
2216
2222
2226
2224
Extended Battery 2230
2228
2230
2232 Wheels

FIG. 22

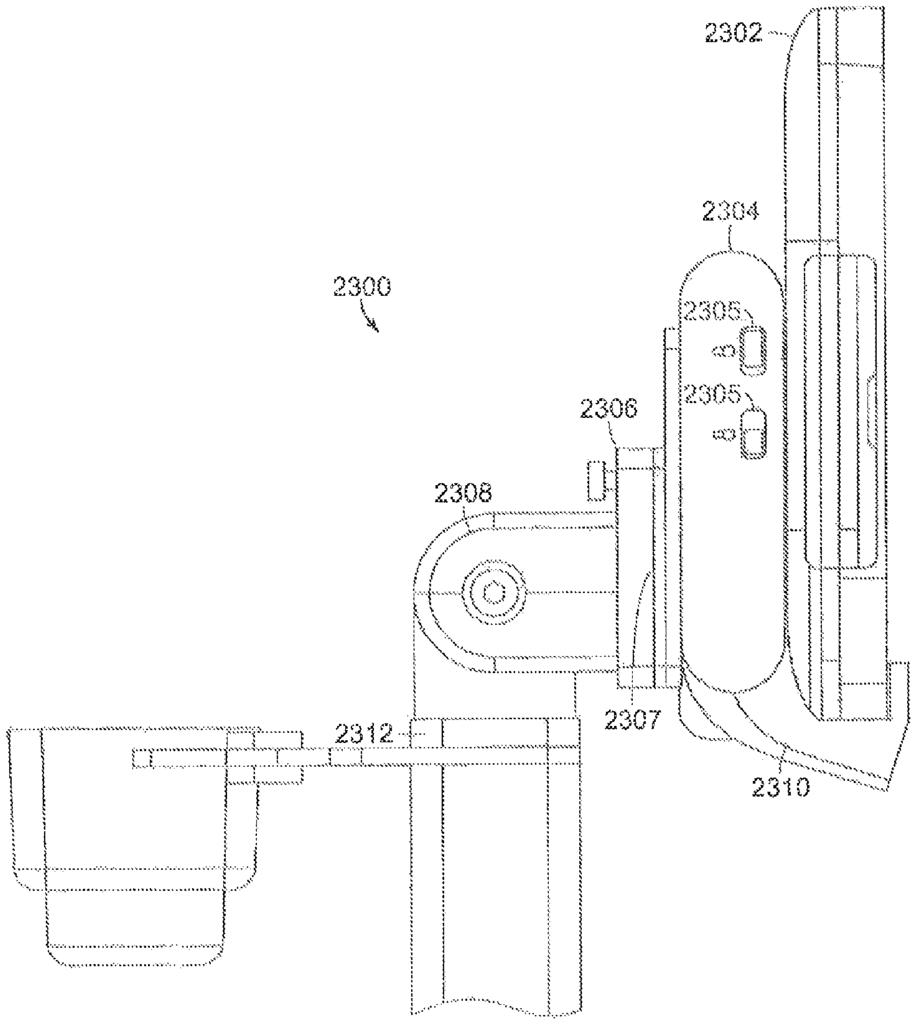


FIG. 23

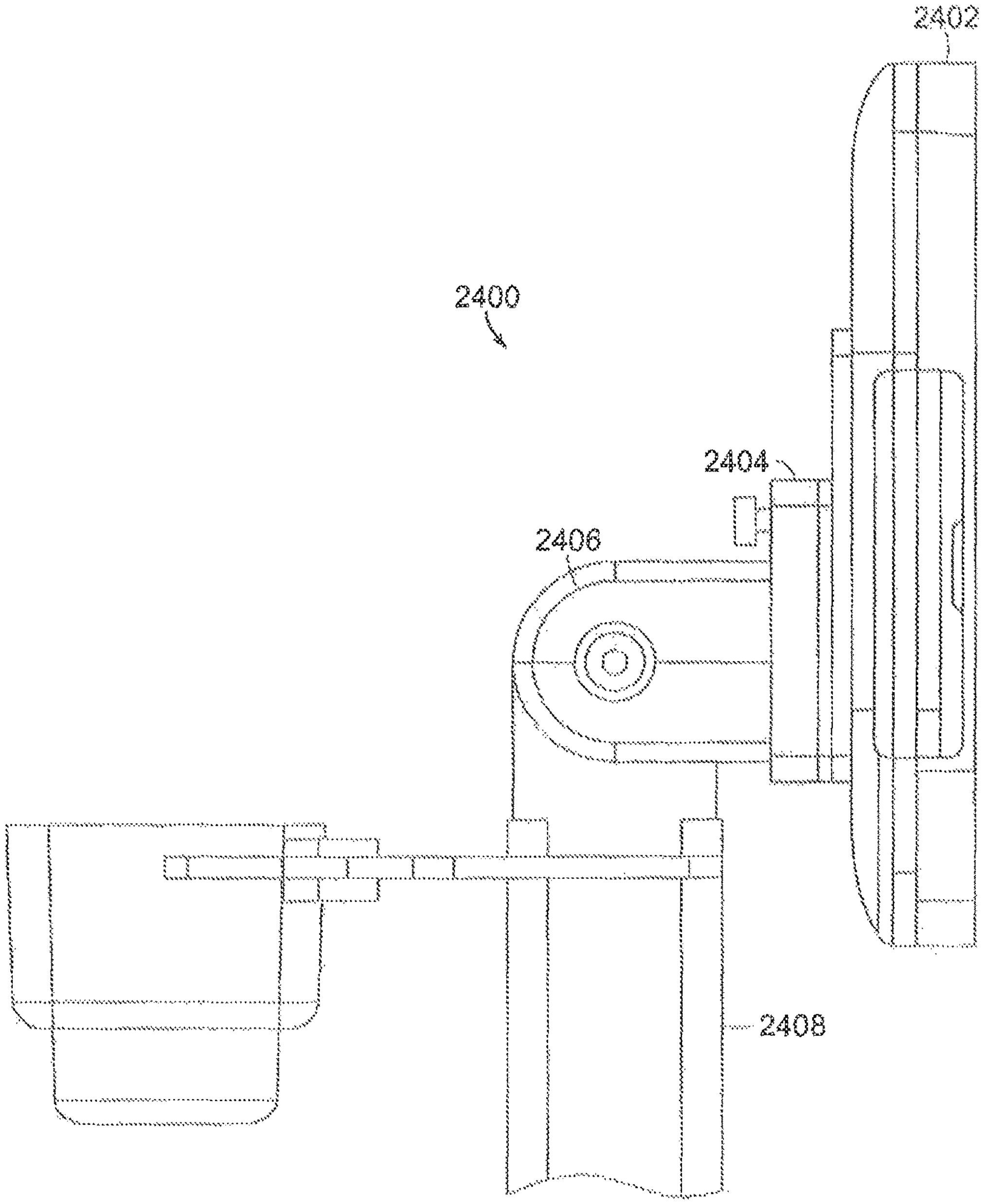


FIG. 24

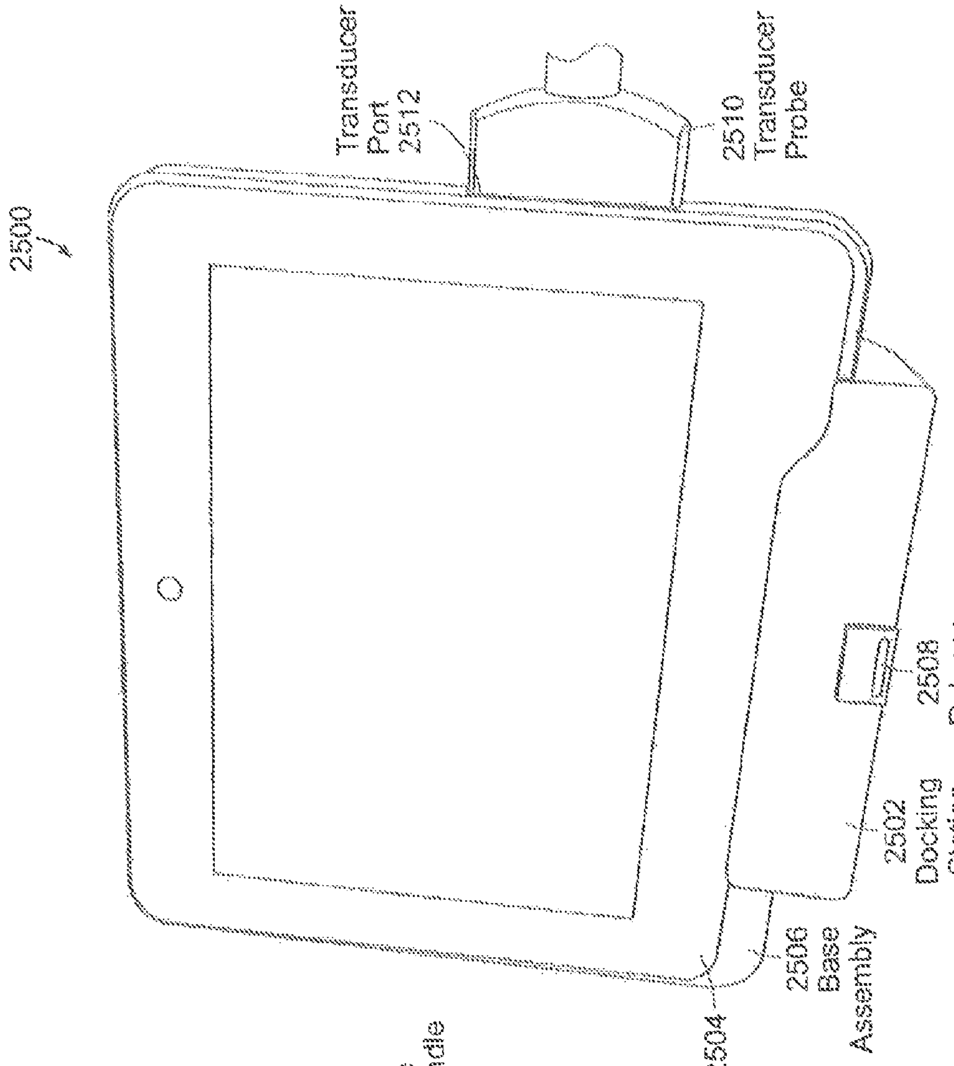


FIG. 25A

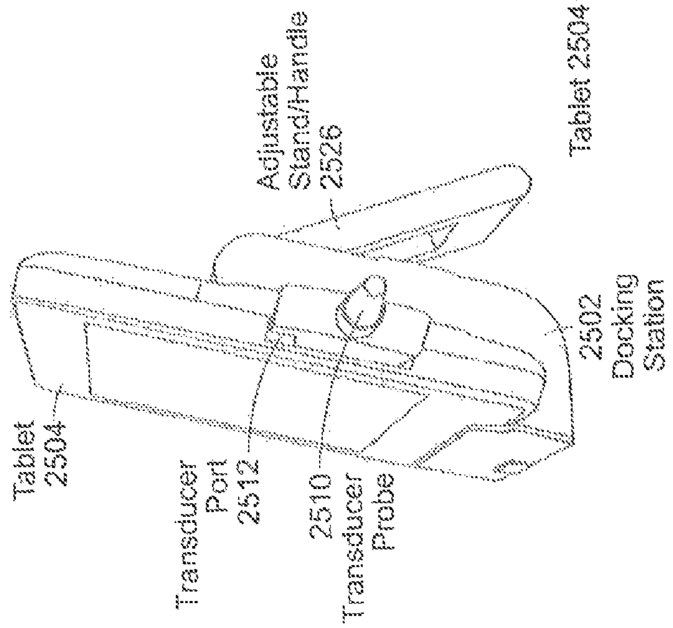


FIG. 25B

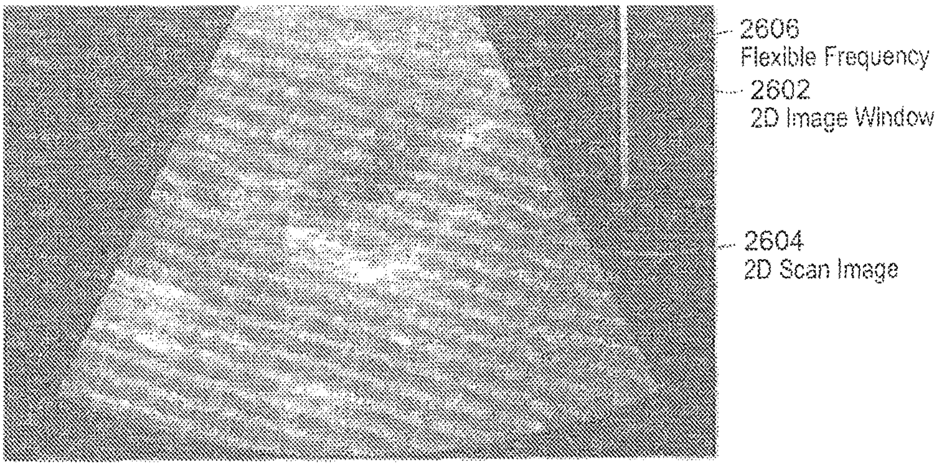

2606
Flexible Frequency
2602
2D Image Window
2604
2D Scan Image

FIG. 26

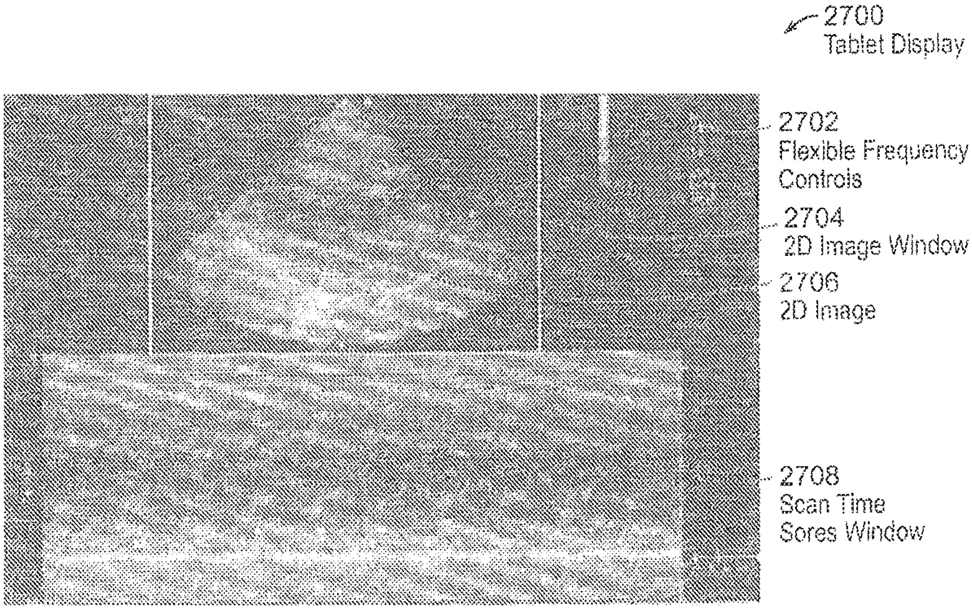

2700
Tablet Display
2702
Flexible Frequency
Controls
2704
2D Image Window
2706
2D Image
2708
Scan Time
Sores Window

FIG. 27

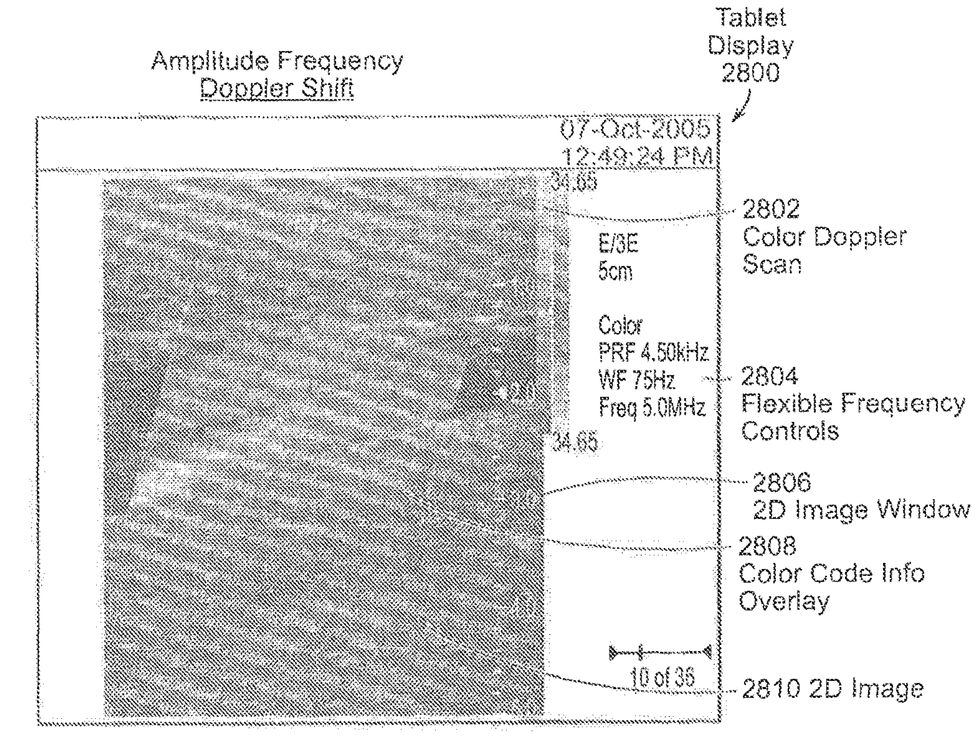

Amplitude Frequency
Doppler Shift
Tablet
Display
2800
07-Oct-2005
12:49:24 PM
34.65
E/3E
5cm
Color
PRF 4.50kHz
WF 75Hz
Freq 5.0MHz
34.65
10 of 36
2802
Color Doppler
Scan
2804
Flexible Frequency
Controls
2806
2D Image Window
2808
Color Code Info
Overlay
2810 2D Image

FIG. 28

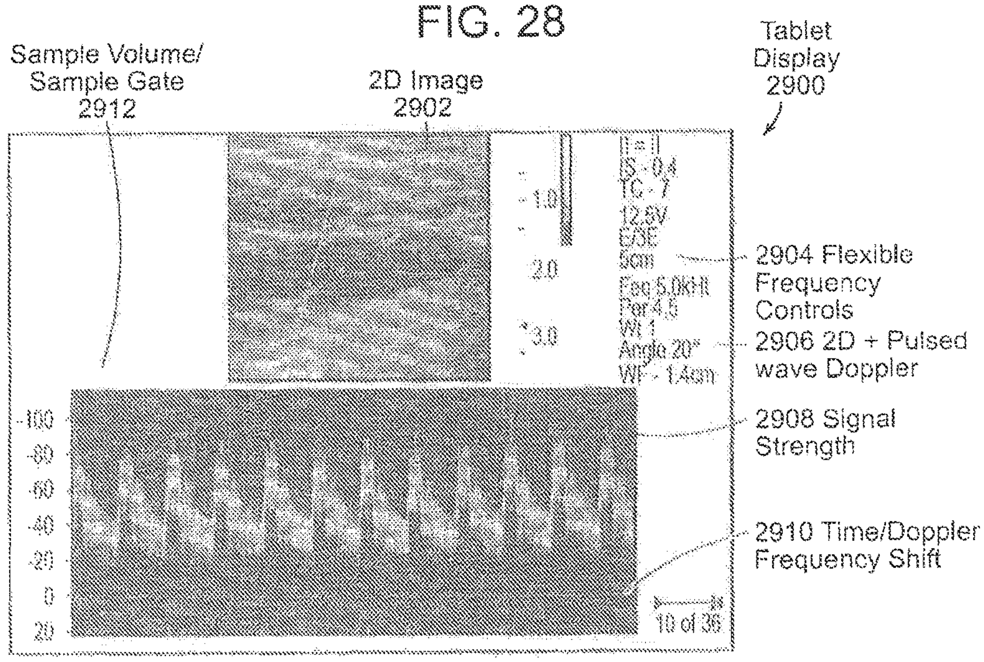

Sample Volume/
Sample Gate
2912
2D Image
2902
Tablet
Display
2900
1.0
2.0
3.0
E/3E
5cm
Angle 20°
-100
-80
-60
-40
-20
0
20
10 of 36
2904 Flexible
Frequency
Controls
2906 2D + Pulsed
wave Doppler
2908 Signal
Strength
2910 Time/Doppler
Frequency Shift

FIG. 29

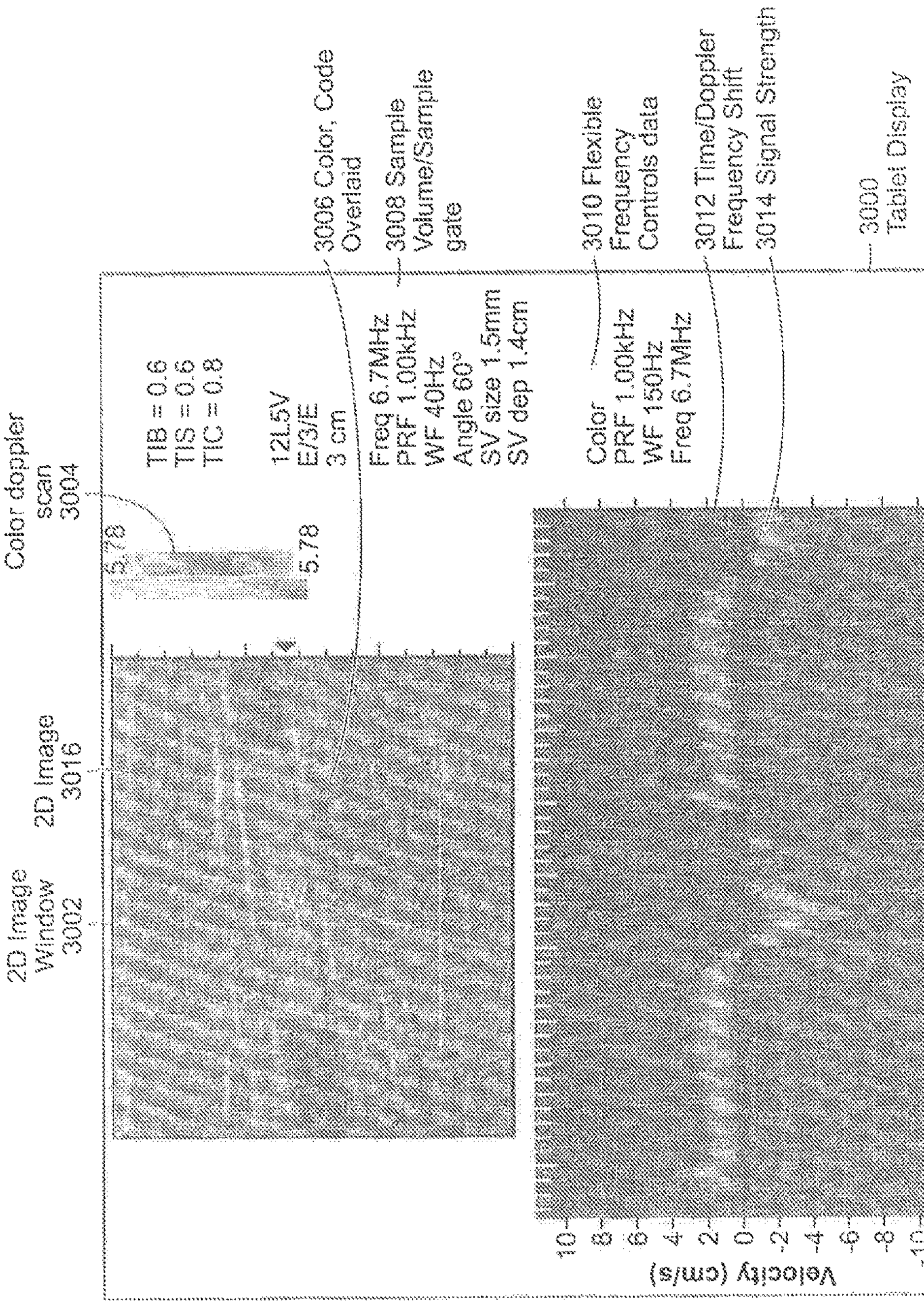

2D Image Window 3002
2D Image 3016
Color doppler scan 3004
5.78
5.78
TIB = 0.6
TIS = 0.6
TIC = 0.8
12L5V
E/3/E
3 cm
Freq 6.7MHz
PRF 1.00kHz
WF 40Hz
Angle 60°
SV size 1.5mm
SV dep 1.4cm
Color
PRF 1.00kHz
WF 150Hz
Freq 6.7MHz
3006 Color, Code Overlaid
3008 Sample Volume/Sample gate
3010 Flexible Frequency Controls data
3012 Time/Doppler Frequency Shift
3014 Signal Strength
3000 Tablet Display
Velocity (cm/s)
10
8
6
4
2
0
-2
-4
-6
-8
-10

FIG. 30

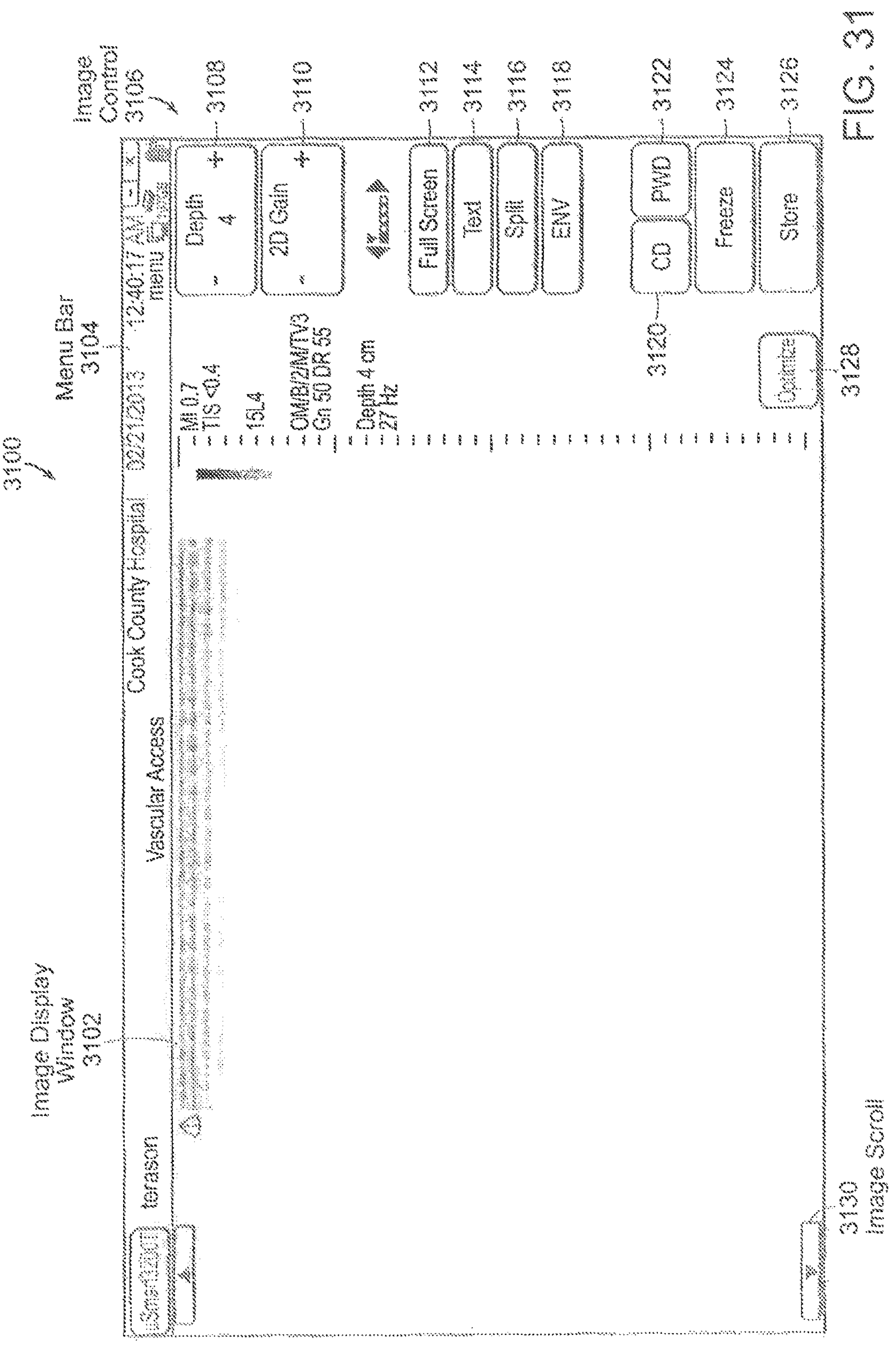

3100
Image Display Window 3102
Menu Bar 3104
Image Control 3106
terason
Vascular Access
Cook County Hospital
02/21/2013
12:40:17 AM
menu
MI 0.7
TIS <0.4
15L4
OM/B/2/M/TV3
Gn 50 DR 55
Depth 4 cm
27 Hz
Depth
4
2D Gain
Full Screen
Text
Split
ENV
CD
PWD
Freeze
Store
Optimize
3108
3110
3112
3114
3116
3118
3120
3122
3124
3126
3128
3130
Image Scroll

FIG. 31

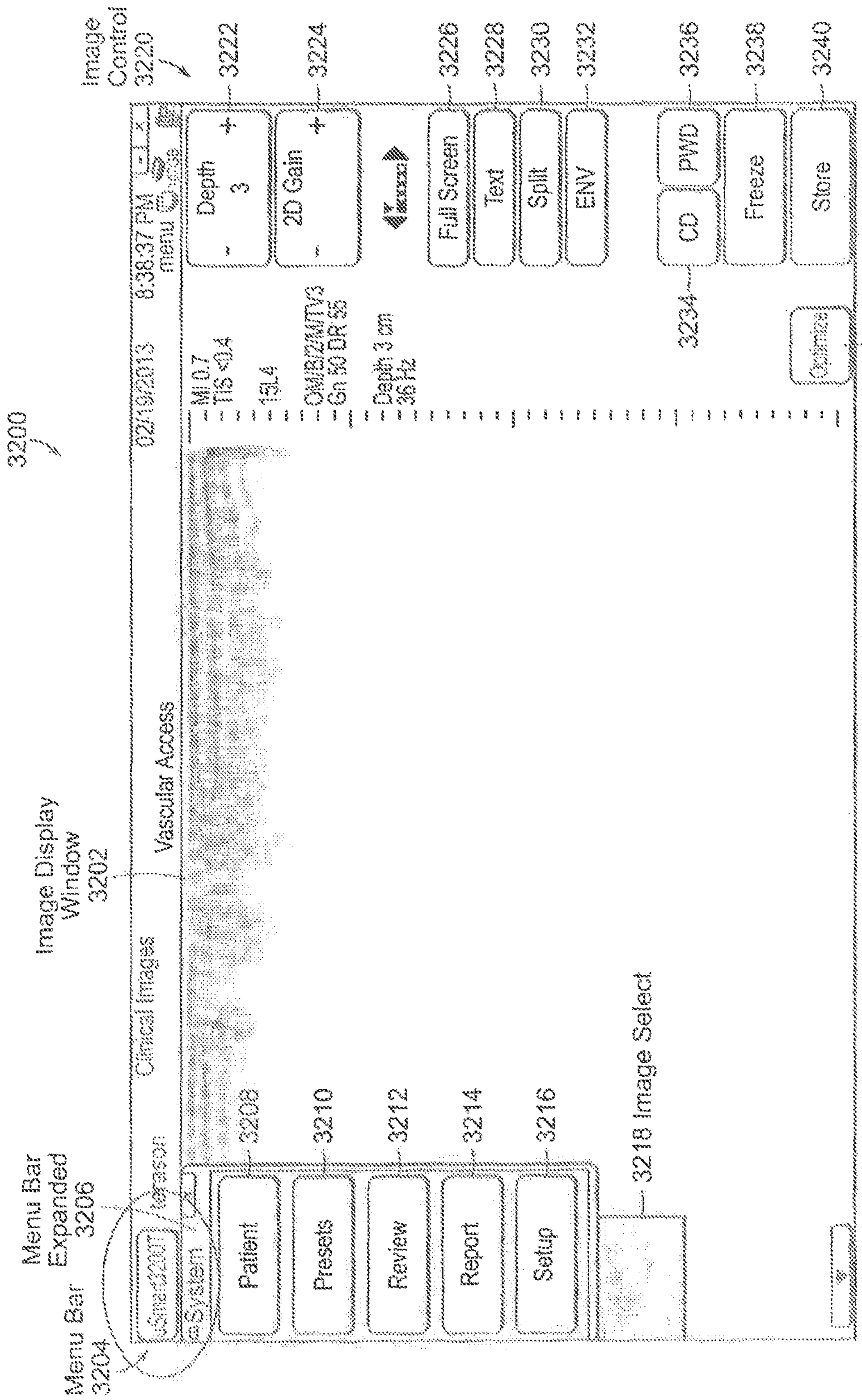

3200
Image Display Window 3202
Menu Bar Expanded 3206
Menu Bar 3204
Image Control 3220
Clinical Images
Vascular Access
02/19/2013
8:38:37 PM
menu
System
Patient
Presets
Review
Report
Setup
3208
3210
3212
3214
3216
3218 Image Select
MI 0.7
TIS <0.4
15L4
Depth 3 cm
36 Hz
Depth
3
2D Gain
Full Screen
Text
Split
ENV
CD
PWD
Freeze
Store
Optimize
3222
3224
3226
3228
3230
3232
3234
3236
3238
3240
3242

FIG. 32

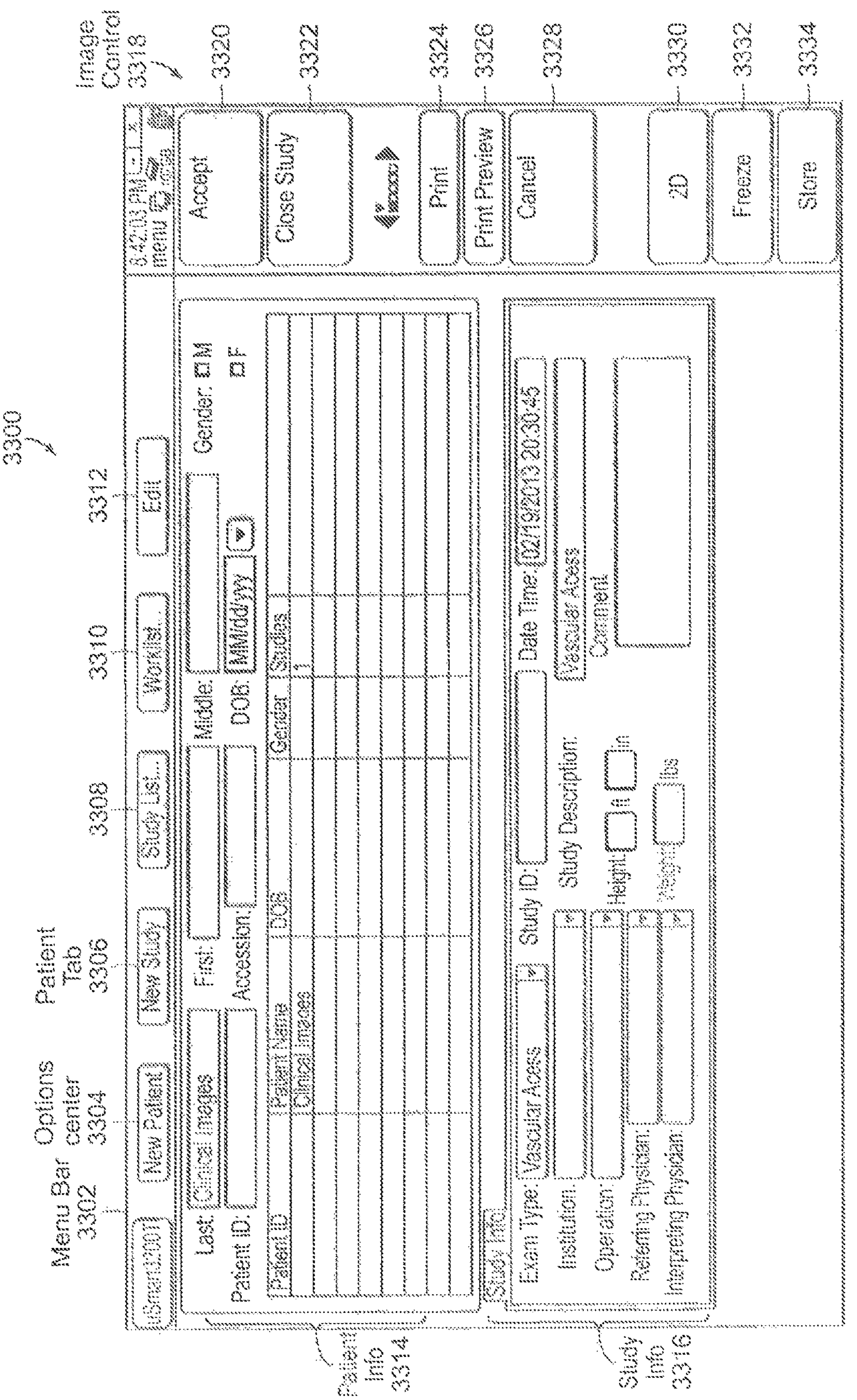

3300
Menu Bar 3302
Options center 3304
Patient Tab 3306
3308
3310
3312
Image Control 3318
3320
3322
3324
3326
3328
3330
3332
3334
New Patient
New Study
Study List...
Worklist...
Edit
Last:
First:
Middle:
Gender: M
F
Patient ID:
Accession:
DOB:
MM/dd/yyy
Patient ID
Patient Name
DOB
Gender
Studies
Clinical Images
Study Info
Exam Type:
Vascular Acess
Study ID:
Date Time:
Institution:
Study Description:
Operation:
Height:
ft
in
Referring Physician:
Weight:
lbs
Interpreting Physician:
Comment:
Accept
Close Study
Print
Print Preview
Cancel
2D
Freeze
Store
Patient Info 3314
Study Info 3316

FIG. 33

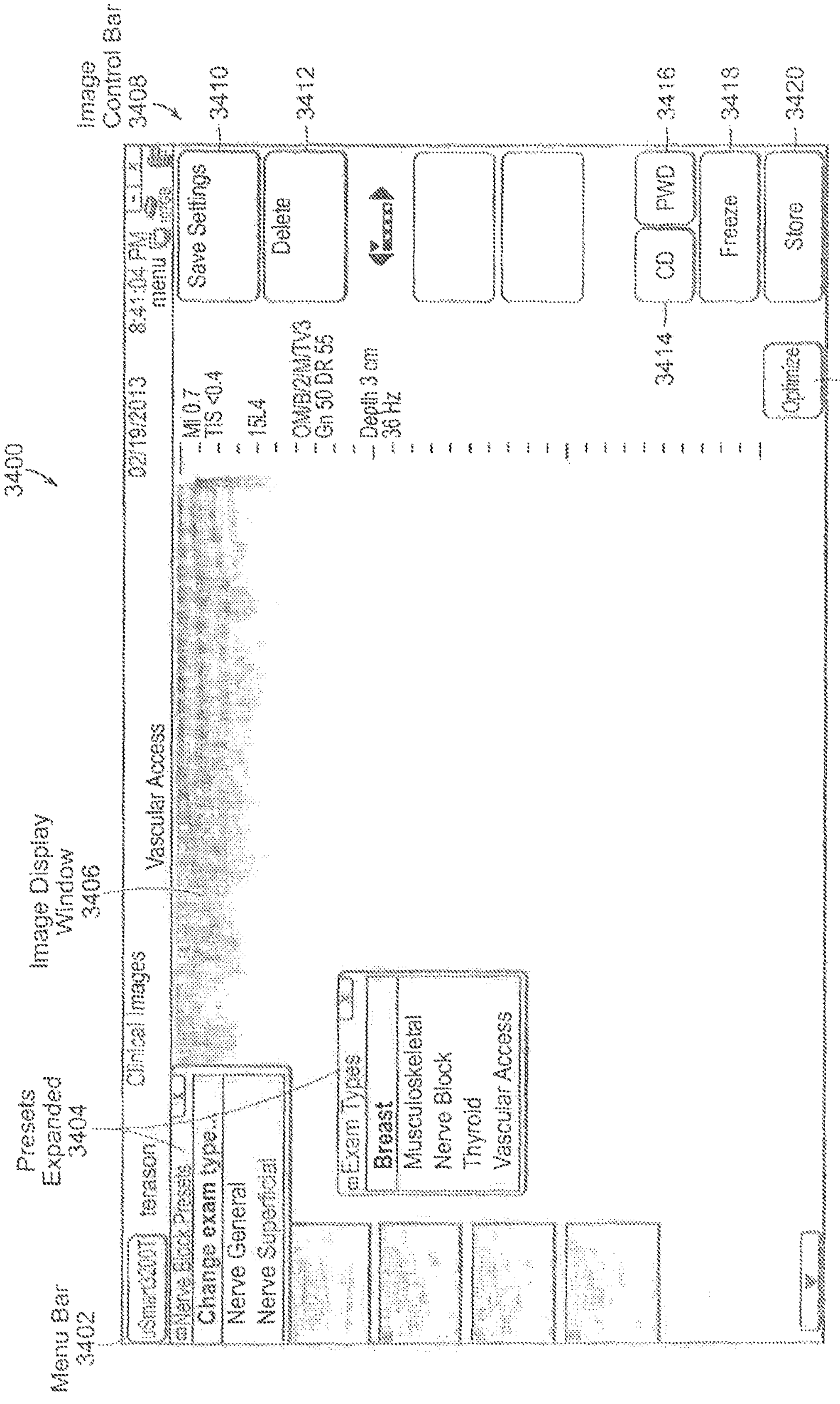

3400
Menu Bar
3402
Presets
Expanded
3404
Image Display
Window
3406
Image
Control Bar
3408
3410
3412
3414
3416
3418
3420
3422
uSmart3300T
terason
Clinical Images
Vascular Access
02/19/2013
8:41:04 PM
menu
Nerve Block Presets
Change exam type...
Nerve General
Nerve Superficial
Exam Types
Breast
Musculoskeletal
Nerve Block
Thyroid
Vascular Access
MI 0.7
TIS <0.4
15L4
OMB/2M/TV3
Gn 50 DR 55
Depth 3 cm
36 Hz
Save Settings
Delete
CD
PWD
Freeze
Store
Optimize

FIG. 34

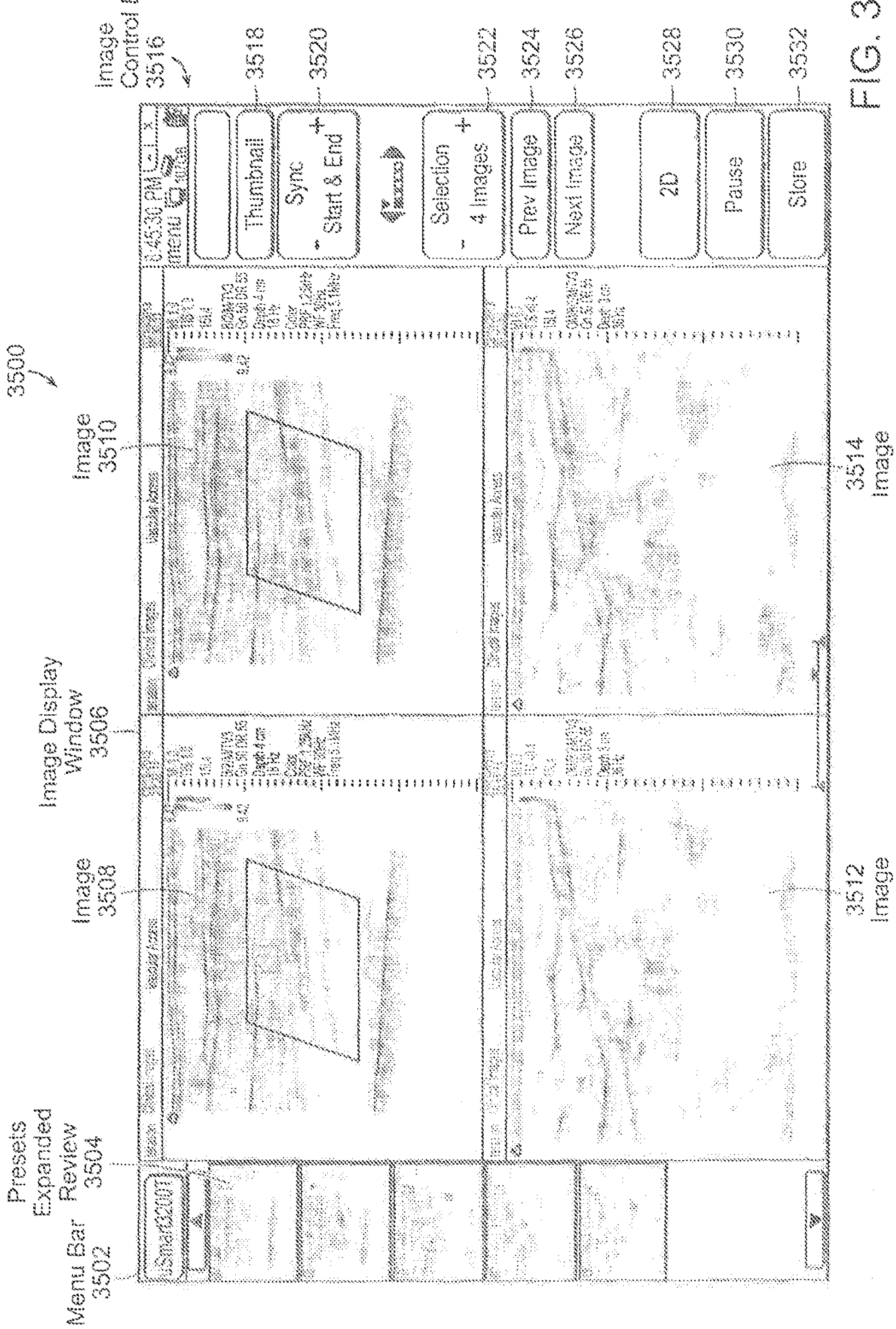

3500
Menu Bar
3502
Presets
Expanded
Review
3504
Image Display
Window
3506
Image
3508
Image
3510
3512
Image
3514
Image
Image
Control Bar
3516
3518
3520
3522
3524
3526
3528
3530
3532
menu
Thumbnail
Sync
Start & End
Selection
4 Images
Prev Image
Next Image
2D
Pause
Store

FIG. 35

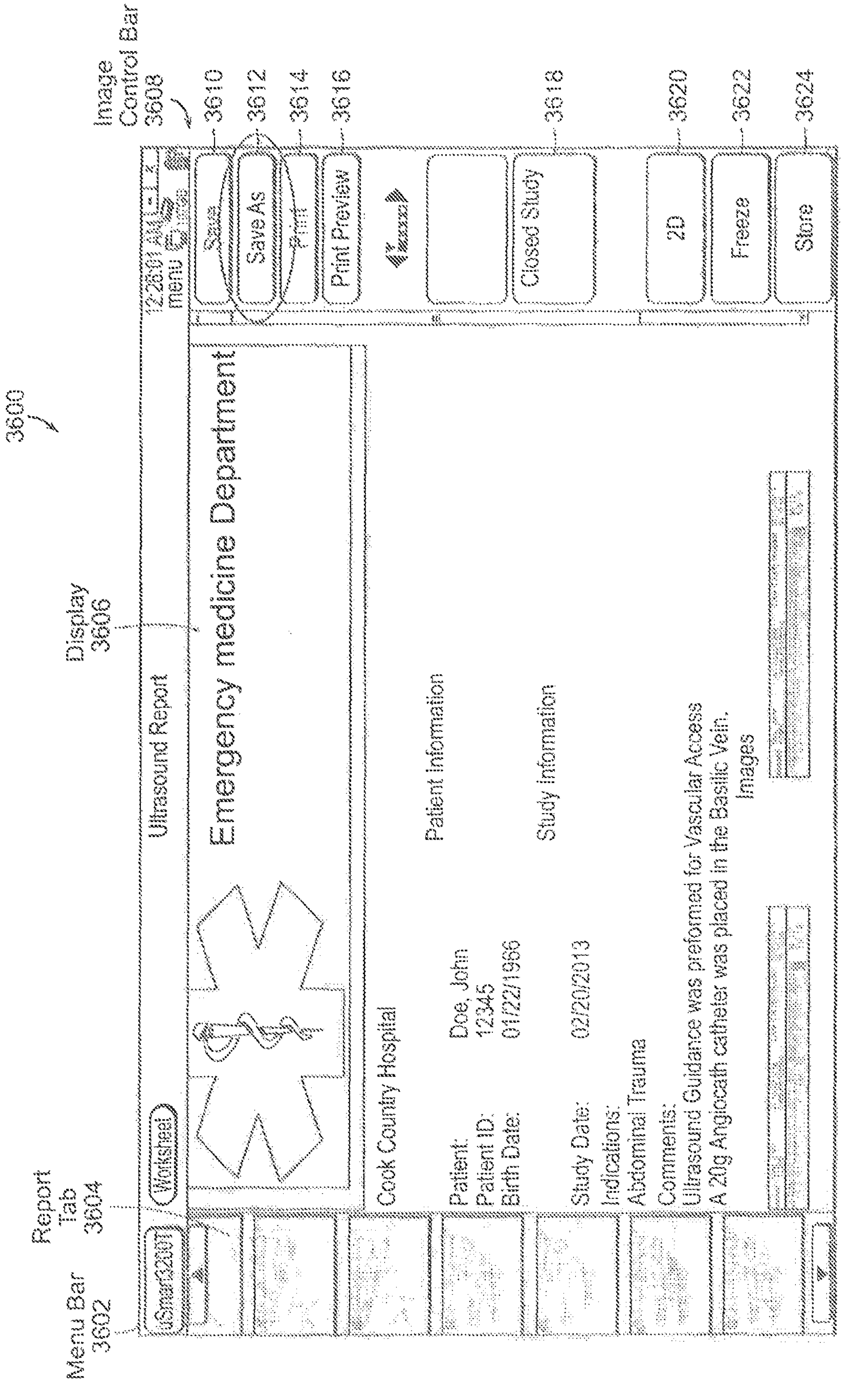

3600
Menu Bar 3602
Report Tab 3604
Display 3606
Image Control Bar 3608
3610
3612
3614
3616
3618
3620
3622
3624
uSmart3200T
Worksheet
Ultrasound Report
12:28:01 AM
menu
Save
Save As
Print
Print Preview
Closed Study
2D
Freeze
Store
Emergency medicine Department
Cook Country Hospital
Patient Information
Patient: Doe, John
Patient ID: 12345
Birth Date: 01/22/1956
Study Information
Study Date: 02/20/2013
Indications:
Abdominal Trauma
Comments:
Ultrasound Guidance was preformed for Vascular Access
A 20g Angiocath catheter was placed in the Basilic Vein.
Images

FIG. 36

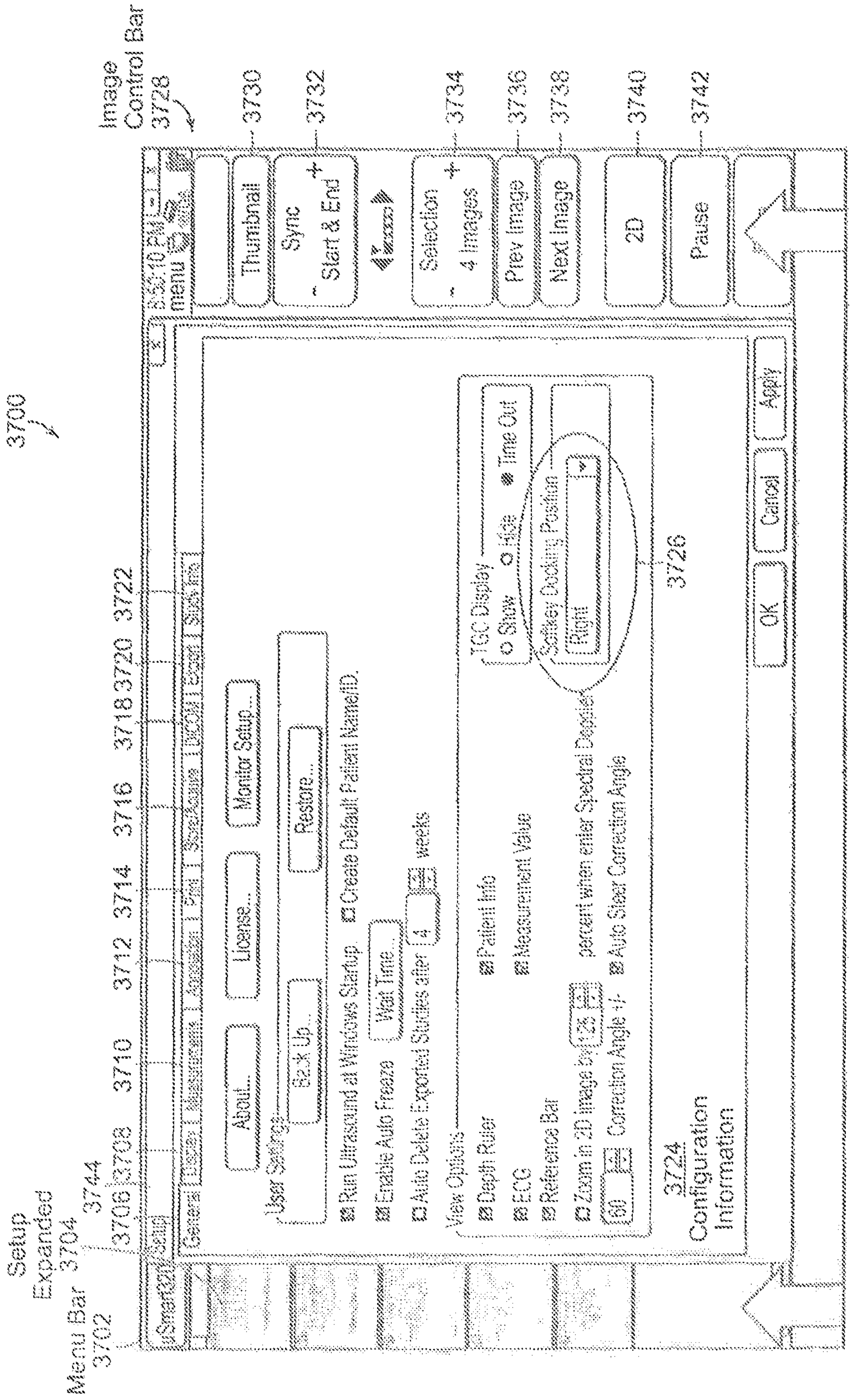

3700
Menu Bar 3702
Setup Expanded 3704
3744
3706
3708
3710
3712
3714
3716
3718
3720
3722
Image Control Bar 3728
3730
3732
3734
3736
3738
3740
3742
3724 Configuration Information
3726
About...
License...
Monitor Setup...
Back Up...
Restore...
Run Ultrasound at Windows Startup
Create Default Patient Name/ID.
Enable Auto Freeze
Wait Time...
Auto Delete Exported Studies after 4 weeks
View Options
Depth Ruler
Patient Info
ECG
Measurement Value
Reference Bar
Auto Steer Correction Angle
Correction Angle +/-
TGC Display
Show
Hide
Time Out
Softkey Docking Position
Right
OK
Cancel
Apply
Thumbnail
Sync
Start & End
Selection
4 Images
Prev Image
Next Image
2D
Pause

FIG. 37A

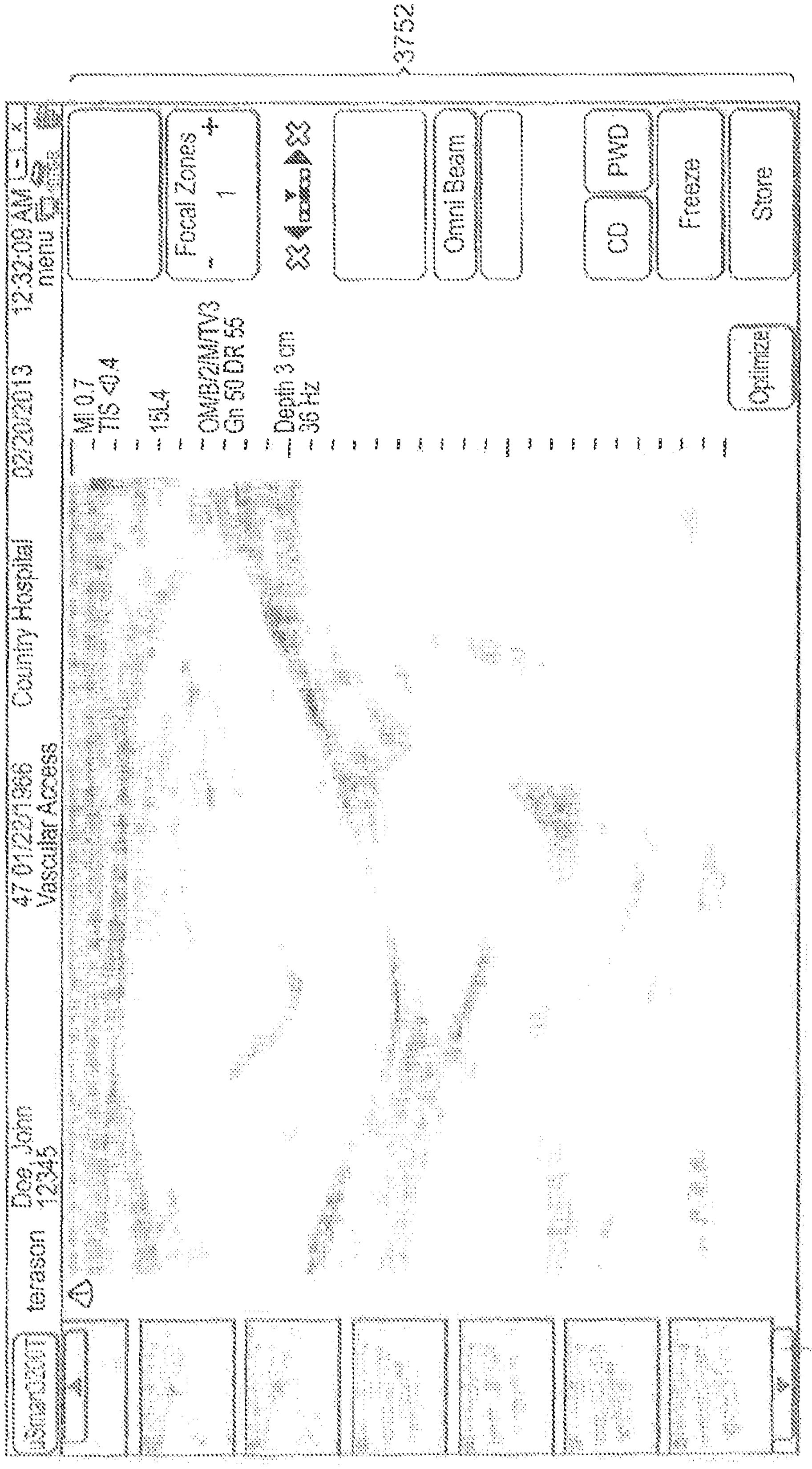

3752
uSmart3300T
terason
Doe, John
12345
47 01/22/1966
Vascular Access
Country Hospital
02/20/2013
12:32:09 AM
menu
MI 0.7
TIS <0.4
15L4
OMB/2/M/TV3
Gn 50 DR 55
Depth 3 cm
36 Hz
Focal Zones
1
Omni Beam
CD
PWD
Freeze
Store
Optimize
3750

FIG. 37B

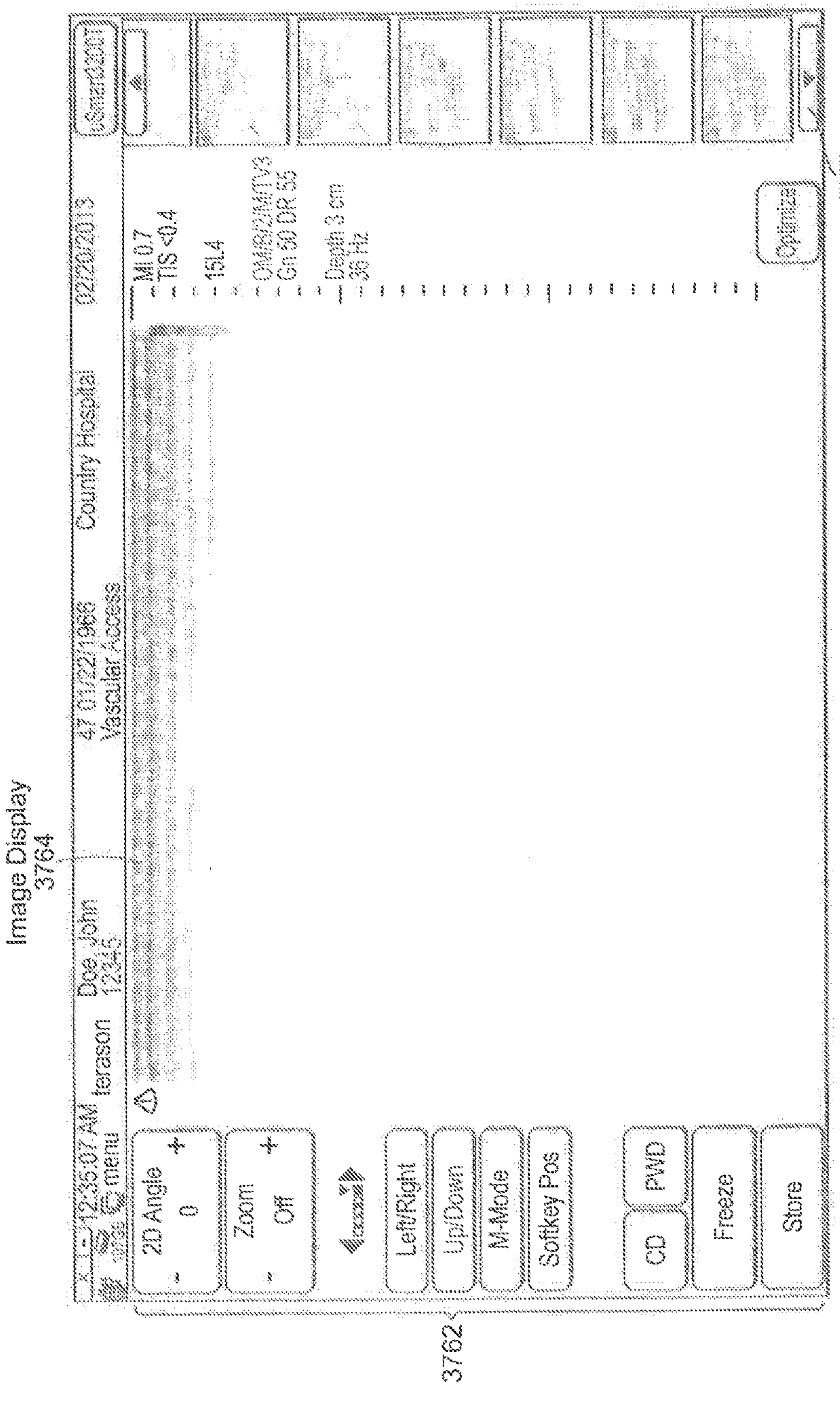


Image Display
3764
3762
12:35:07 AM
menu
terason
Doe, John
12345
47 01/22/1966
Vascular Access
Country Hospital
02/20/2013
2D Angle
0
Zoom
Off
Left/Right
Up/Down
M-Mode
Softkey Pos
CD
PWD
Freeze
Store
MI 0.7
TIS <0.4
15L4
Gn 50 DR 55
Depth 3 cm
36 Hz
Optimize
3760
Softkey Control

FIG. 37C

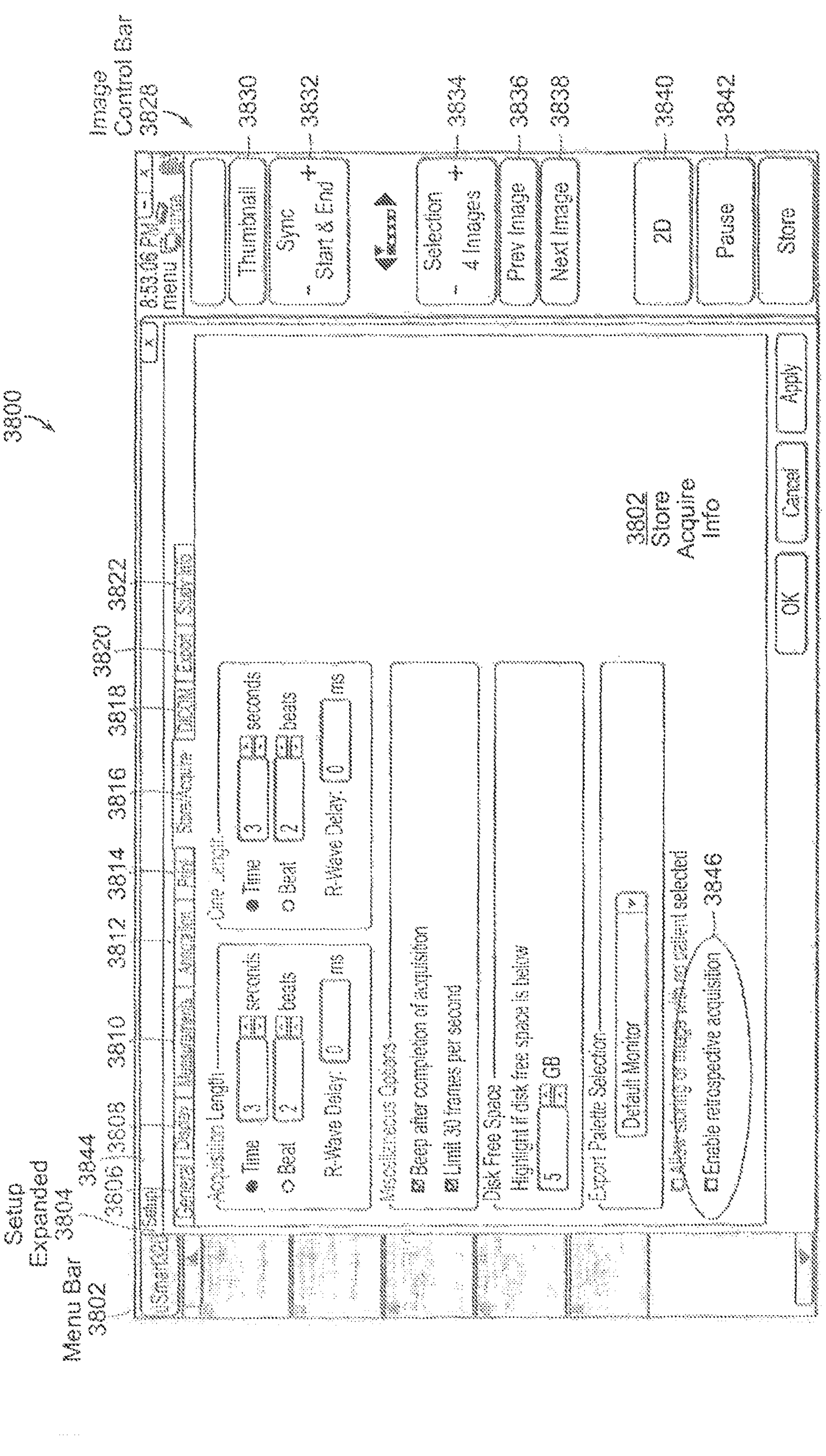


FIG. 38

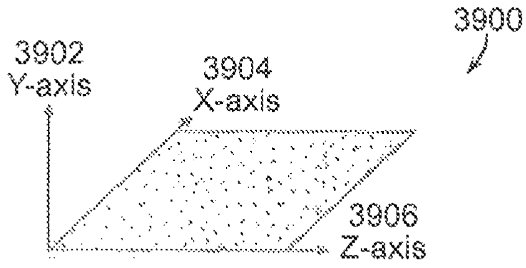


FIG. 39A

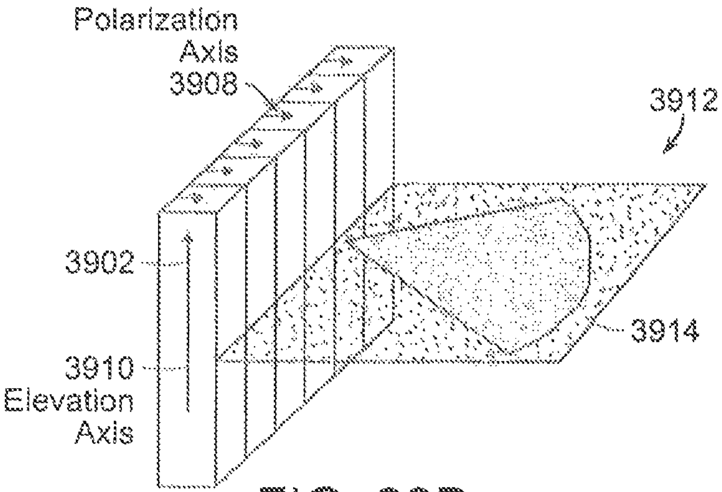


FIG. 39B

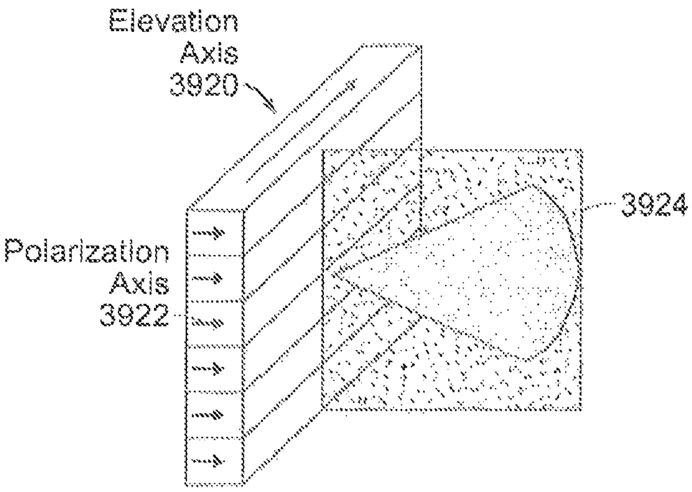


FIG. 39C

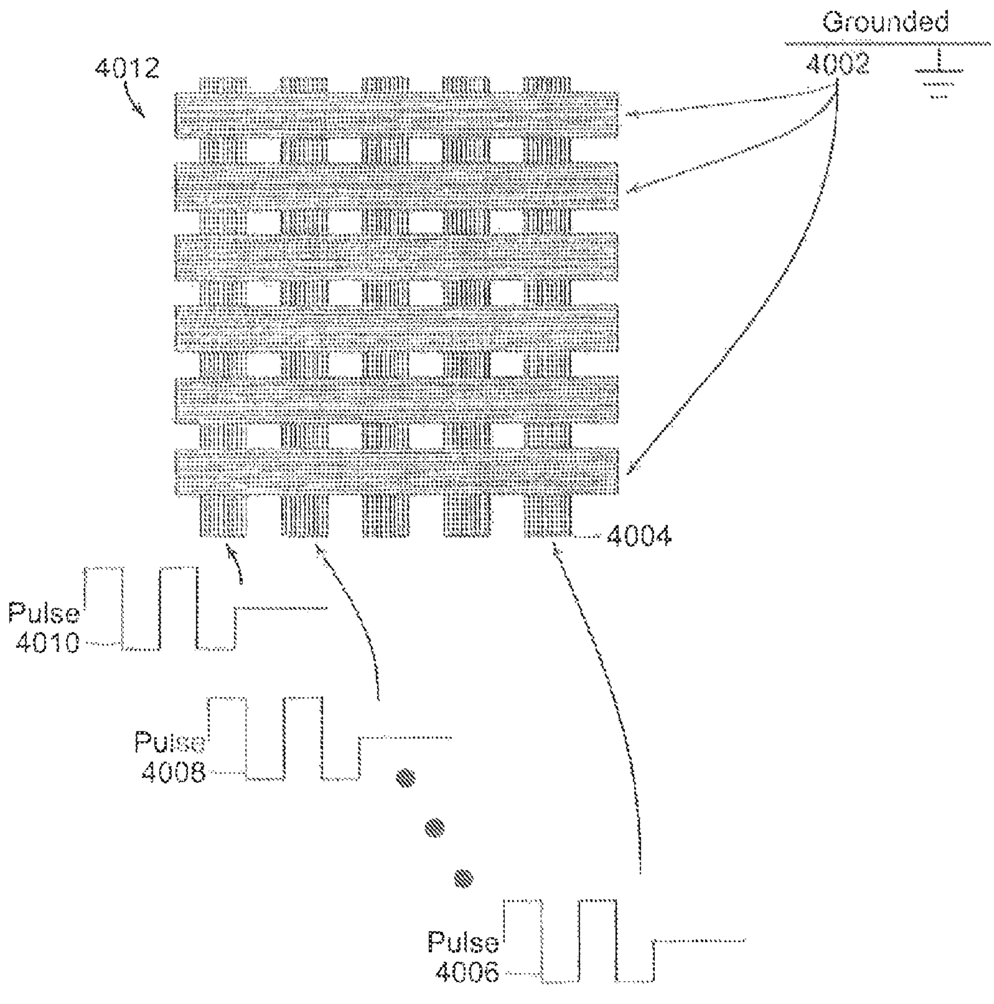


FIG. 40

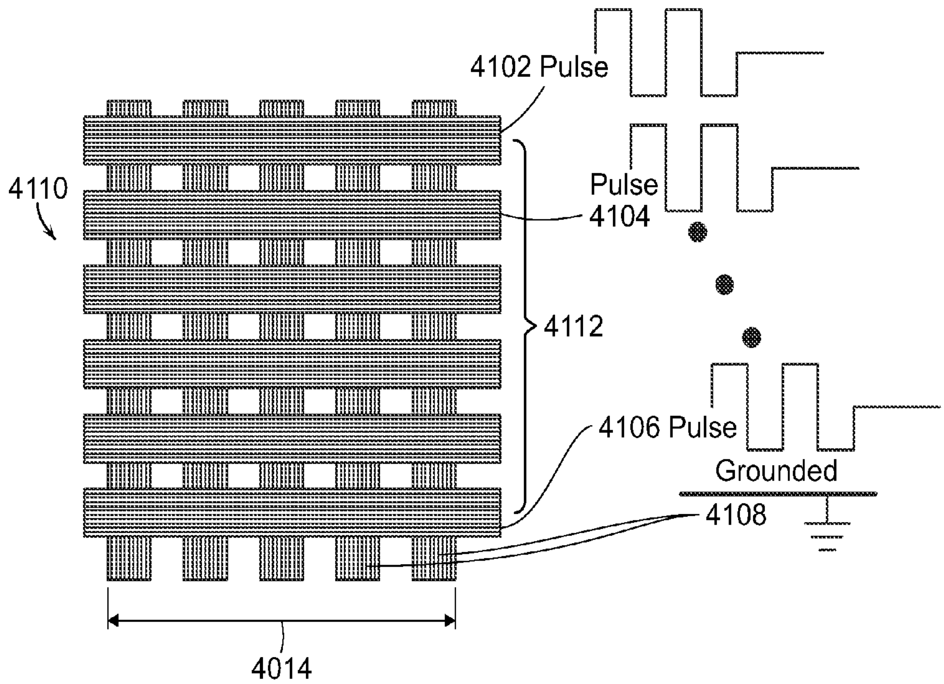

4102 Pulse
Pulse
4104
4110
4112
4106 Pulse
Grounded
4108
4014

FIG. 41

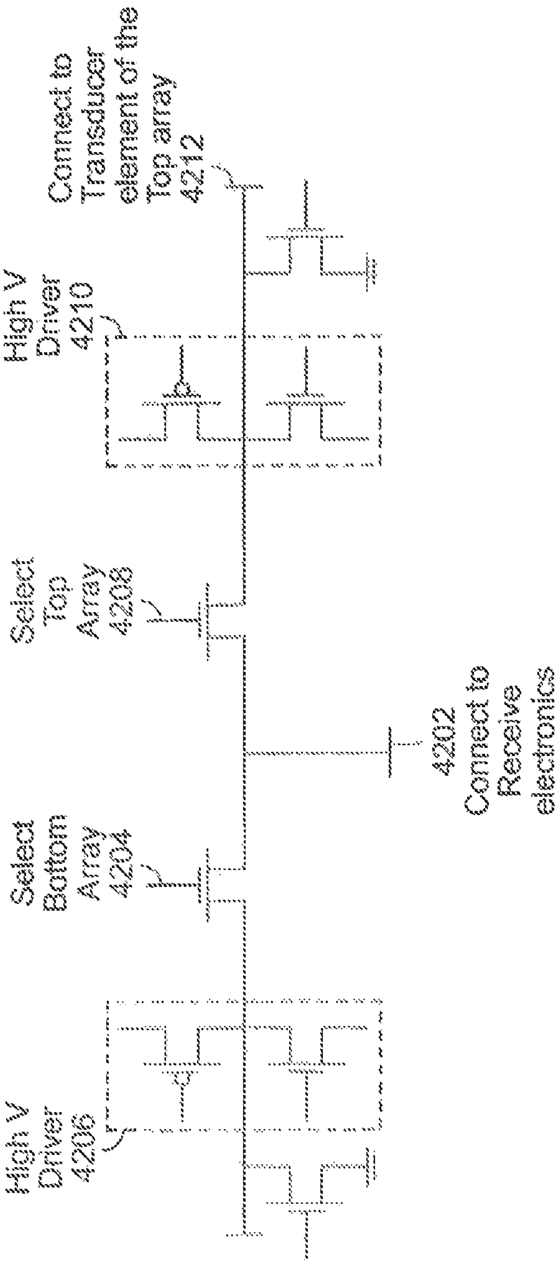

Connect to Transducer element of the Top array
4212
High V Driver
4210
Select Top Array
4208
4202
Connect to Receive electronics
Select Bottom Array
4204
High V Driver
4206

FIG. 42

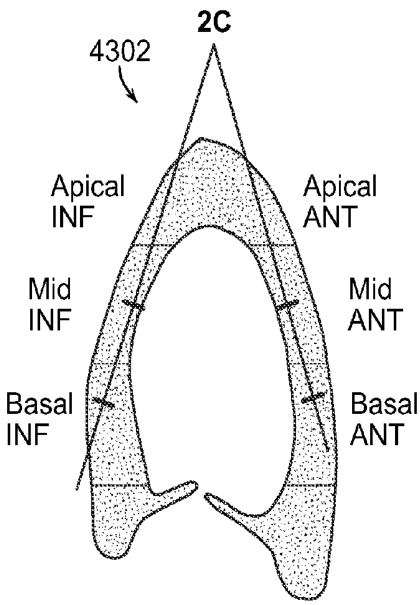


FIG. 43A

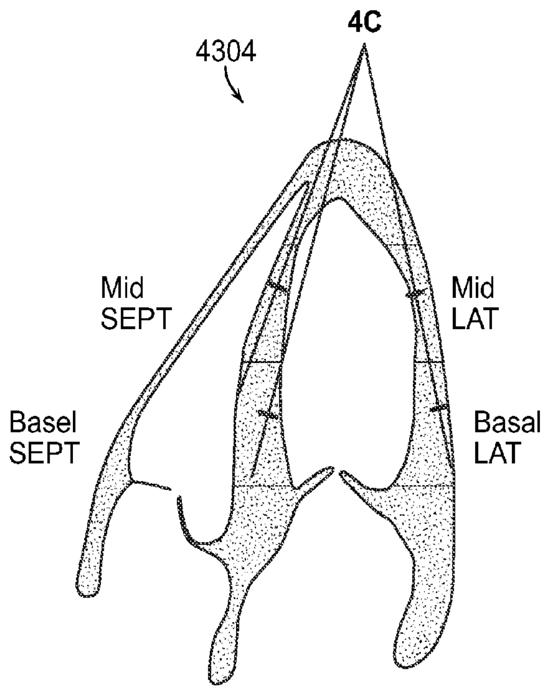


FIG. 43B

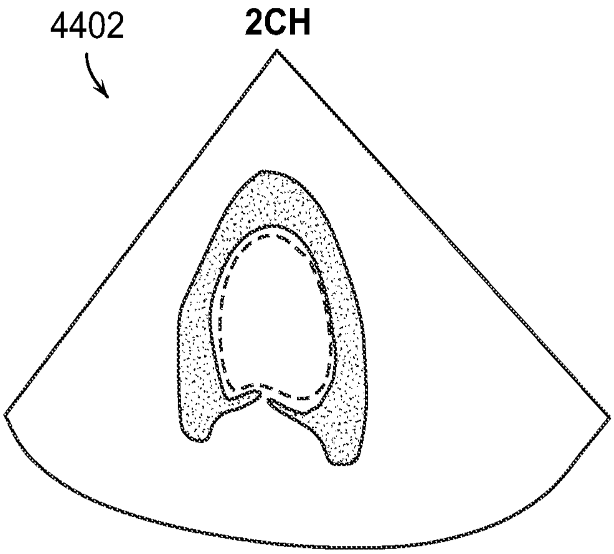


FIG. 44A

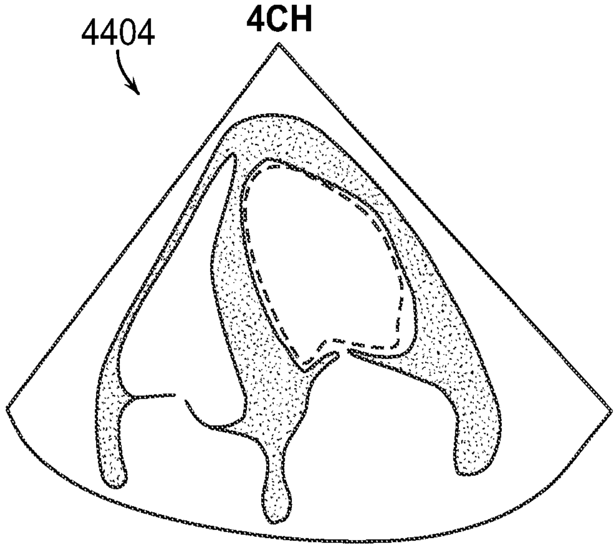


FIG. 44B

TABLET ULTRASOUND SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of PCT Application PCT/US2013/033941 filed Mar. 26, 2013, and of U.S. application Ser. No. 13/838,694 filed Mar. 15, 2013, and claims priority to U.S. Provisional Application No. 61/615,627, filed Mar. 26, 2012 and U.S. Provisional Application No. 61/704,254, filed Sep. 21, 2012, these applications being incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

Medical ultrasound imaging has become an industry standard for many medical imaging applications. In recent years, there has been an increasing need for medical ultrasound imaging equipment that is portable to allow medical personnel to easily transport the equipment to and from hospital and/or field locations, and more user-friendly to accommodate medical personnel who may possess a range of skill levels.

Conventional medical ultrasound imaging equipment typically includes at least one ultrasound probe/transducer, a keyboard and/or a knob, a computer, and a display. In a typical mode of operation, the ultrasound probe/transducer generates ultrasound waves that can penetrate tissue to different depths based on frequency level, and receives ultrasound waves reflected back from the tissue. Further, medical personnel can enter system inputs to the computer via the keyboard and/or the knob, and view ultrasound images of tissue structures on the display.

However, conventional medical ultrasound imaging equipment that employ such keyboards and/or knobs can be bulky, and therefore may not be amenable to portable use in hospital and/or field locations. Moreover, because such keyboards and/or knobs typically have uneven surfaces, they can be difficult to keep clean in hospital and/or field environments, where maintenance of a sterile field can be crucial to patient health. Some conventional medical ultrasound imaging equipment have incorporated touch screen technology to provide a partial user input interface. However, conventional medical ultrasound imaging equipment that employ such touch screen technology generally provide only limited touch screen functionality in conjunction with a traditional keyboard and/or knob, and can therefore not only be difficult to keep clean, but also complicated to use.

SUMMARY OF THE INVENTION

In accordance with the present application, systems and methods of medical ultrasound imaging are disclosed. The presently disclosed systems and methods of medical ultrasound imaging employ medical ultrasound imaging equipment that includes a handheld housing in a tablet form factor, and a touch screen display disposed on a front panel of the housing. The touch screen display includes a multi-touch touchscreen that can recognize and distinguish one or more single, multiple, and/or simultaneous touches on a surface of the touch screen display, thereby allowing the use of gestures, ranging from simple single point gestures to complex multipoint moving gestures, as user inputs to the medical ultrasound imaging equipment.

In accordance with one aspect, exemplary medical ultrasound imaging system includes a housing having a front panel and a rear panel rigidly mounted to each other in

parallel planes, a touch screen display, a computer having at least one processor and at least one memory, an ultrasound beamforming system, and a battery. The housing of the medical ultrasound imaging equipment is implemented in a tablet form factor. The touch screen display is disposed on the front panel of the housing, and includes a multi-touch LCD touch screen that can recognize and distinguish one or more single, multiple, and/or simultaneous touches or gestures on a surface of the touch screen display. The computer, the ultrasound beamforming system or engine, and the battery are operatively disposed within the housing. The medical ultrasound imaging equipment can use a Firewire connection operatively connected between the computer and the ultrasound engine within the housing and a probe connector having a probe attach/detach lever to facilitate the connection of at least one ultrasound probe/transducer. In addition, the exemplary medical ultrasound imaging system includes an I/O port connector and a DC power input.

In an exemplary mode of operation, medical personnel can employ simple single point gestures and/or more complex multipoint gestures as user inputs to the multi-touch LCD touch screen for controlling operational modes and/or functions of the exemplary medical ultrasound imaging equipment. Such single point/multipoint gestures can correspond to single and/or multipoint touch events that are mapped to one or more predetermined operations that can be performed by the computer and/or the ultrasound engine. Medical personnel can make such single point/multipoint gestures by various finger, palm, and/or stylus motions on the surface of the touch screen display. The multi-touch LCD touch screen receives the single point/multipoint gestures as user inputs, and provides the user inputs to the computer, which executes, using the processor, program instructions stored in the memory to carry out the predetermined operations associated with the single point/multipoint gestures, at least at some times, in conjunction with the ultrasound engine. Such single point/multipoint gestures on the surface of the touch screen display can include, but are not limited to, a tap gesture, a pinch gesture, a flick gesture, a rotate gesture, a double tap gesture, a spread gesture, a drag gesture, a press gesture, a press and drag gesture, and a palm gesture. In contrast to existing ultrasound systems that rely on numerous control features operated by mechanical switching, keyboard elements, or touchpad trackball interface, preferred embodiments of the present invention employ a single on/off switch. All other operations have been implemented using touchscreen controls. Moreover, the preferred embodiments employ a capacitive touchscreen display that is sufficiently sensitive to detect touch gestures actuated by bare fingers of the user as well as gloved fingers of the user. Often medical personnel must wear sterilized plastic gloves during medical procedures. Consequently, it is highly desirable to provide a portable ultrasound device that can be used by gloved hands; however, this has previously prevented the use of touchscreen display control functions in ultrasound systems for many applications requiring sterile precautions. Preferred embodiments of the present invention provide control of all ultrasound imaging operations by gloved personnel on the touchscreen display using the programmed touch gestures.

In accordance with an exemplary aspect, at least one flick gesture may be employed to control the depth of tissue penetration of ultrasound waves generated by the ultrasound probe/transducer. For example, a single flick gesture in the "up" direction on the touch screen display surface can increase the penetration depth by one (1) centimeter or any other suitable amount, and a single flick gesture in the "down" direction on the touch screen display surface can decrease the penetration depth by one (1) centimeter or any other suitable amount. Further, a drag gesture in the "up" or "down" direction on the touch screen display surface can increase or decrease the penetration depth in multiples of one (1) centimeter or any other suitable amount. Additional operational modes and/or functions controlled by specific single point/multipoint gestures on the touch screen display surface can include, but are not limited to, freeze/store operations, 2-dimensional mode operations, gain control, color control, split screen control, PW imaging control, cine/time-series image clip scrolling control, zoom and pan control, full screen control, Doppler and 2-dimensional beam steering control, and/or body marking control. At least some of the operational modes and/or functions of the exemplary medical ultrasound imaging equipment can be controlled by one or more touch controls implemented on the touch screen display in which beamforming parameters can be reset by moving touch gestures. Medical personnel can provide one or more specific single point/multipoint gestures as user inputs for specifying at least one selected subset of the touch controls to be implemented, as required and/or desired, on the touch screen display. A larger number of touchscreen controls enable greater functionality when operating in full screen mode when a few or more virtual buttons or icons are available for use.

In accordance with another exemplary aspect, a press gesture can be employed inside a region of the touch screen display, and, in response to the press gesture, a virtual window can be provided on the touch screen display for displaying at least a magnified portion of an ultrasound image displayed on the touch screen display. In accordance with still another exemplary aspect, a press and drag gesture can be employed inside the region of the touch screen display, and, in response to the press and drag gesture, a predetermined feature of the ultrasound image can be traced. Further, a tap gesture can be employed inside the region of the touch screen display, substantially simultaneously with a portion of the press and drag gesture, and, in response to the tap gesture, the tracing of the predetermined feature of the ultrasound image can be completed. These operations can operate in different regions of a single display format, so that a moving gesture within a region of interest within the image, for example, may perform a different function than the same gesture executed within the image but outside the region of interest.

By providing medical ultrasound imaging equipment with a multi-touch touchscreen, medical personnel can control the equipment using simple single point gestures and/or more complex multipoint gestures, without the need of a traditional keyboard or knob. Because the multi-touch touch screen obviates the need for a traditional keyboard or knob, such medical ultrasound imaging equipment is easier to keep clean in hospital and/or field environments, provides an intuitive user friendly interface, while providing fully functional operations. Moreover, by providing such medical ultrasound imaging equipment in a tablet form factor, medical personnel can easily transport the equipment between hospital and/or field locations.

Certain exemplary embodiments provide a multi-chip module for an ultrasound engine of a portable medical ultrasound imaging system, in which a transmit/receive (TR) chip, a pre-amp/time gain compensation (TGC) chip and a beamformer chip are assembled in a vertically stacked configuration. The transmission circuit provides high voltage electrical driving pulses to the transducer elements to generate a transmit beam. As the transmit chip operates at voltages greater than 80V, a CMOS process utilizing a 1 micron design rule has been utilized for the transmit chip and a submicron design rule has been utilized for the low-voltage receiving circuits (less than 5V).

Preferred embodiments of the present invention utilize a submicron process to provide integrated circuits with sub-circuits operating at a plurality of voltages, for example, 2.5V, 5V and 60V or higher. These features can be used in conjunction with a bi-plane transducer probe in accordance with certain preferred embodiments of the invention.

Thus, a single IC chip can be utilized that incorporates high voltage transmission, low voltage amplifier/TGC and low voltage beamforming circuits in a single chip. Using a 0.25 micron design rule, this mixed signal circuit can accommodate beamforming of 32 transducer channels in a chip area less than 0.7×0.7 (0.49) cm^2. Thus, 128 channels can be processed using four 32 channel chips in a total circuit board area of less than 1.5×1.5 (2.25) cm^2.

The term "multi-chip module," as used herein, refers to an electronic package in which multiple integrated circuits (IC) are packaged with a unifying substrate, facilitating their use as a single component, i.e., as a higher processing capacity IC packaged in a much smaller volume. Each IC can comprise a circuit fabricated in a thinned semiconductor wafer. Exemplary embodiments also provide an ultrasound engine including one or more such multi-chip modules, and a portable medical ultrasound imaging system including an ultrasound engine circuit board with one or more multi-chip modules. Exemplary embodiments also provide methods for fabricating and assembling multi-chip modules as taught herein. Vertically stacking the TR chip, the pre-amp/TGC chip, and the beamformer chip on a circuit board minimizes the packaging size (e.g., the length and width) and the footprint occupied by the chips on the circuit board.

The TR chip, the pre-amp/TGC chip, and the beamformer chip in a multi-chip module may each include multiple channels (for example, 8 channels per chip to 64 channels per chip). In certain embodiments, the high-voltage TR chip, the pre-amp/TGC chip, and the sample-interpolate receive beamformer chip may each include 8, 16, 32, 64 channels. In a preferred embodiment, each circuit in a two layer beamformer module has 32 beamformer receive channels to provide a 64 channel receiving beamformer. A second 64 channel two layer module can be used to form a 128 channel handheld tablet ultrasound device having an overall thickness of less than 2 cm. A transmit multi-chip beamformer can also be used having the same or similar channel density in each layer.

Exemplary numbers of chips vertically integrated in a multi-chip module may include, but are not limited to, two, three, four, five, six, seven, eight, and the like. In one embodiment of an ultrasound device, a single multi-chip module is provided on a circuit board of an ultrasound engine that performs ultrasound-specific operations. In other embodiments, a plurality of multi-chip modules are provided on a circuit board of an ultrasound engine. The plurality of multi-chip modules may be stacked vertically on top of one another on the circuit board of the ultrasound engine to further minimize the packaging size and the footprint of the circuit board.

Providing one or more multi-chip modules on a circuit board of an ultrasound engine achieves a high channel count while minimizing the overall packaging size and footprint. For example, a 128-channel ultrasound engine circuit board can be assembled, using multi-chip modules, within exemplary planar dimensions of about 10 cm× about 10 cm, which is a significant improvement over the much larger space requirements of conventional ultrasound circuits. A single circuit board of an ultrasound engine including one or more multi-chip modules may have 16 to 128 channels in some embodiments. In certain embodiments, a single circuit board of an ultrasound engine including one or more multi-chip modules may have 16, 32, 64, 128 or 192 channels, and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects, features, and advantages of exemplary embodiments will become more apparent and may be better understood by referring to the following description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a plan view of exemplary medical ultrasound imaging equipment, in accordance with an exemplary embodiment of the present application;

FIGS. **2**A and **2**B are side views of the medical ultrasound imaging system in accordance with preferred embodiments of the invention;

FIG. **3**AA-**3**AL illustrates exemplary single point and multipoint gestures that can be employed as user inputs to the medical ultrasound imaging system in accordance with preferred embodiments of the invention;

FIG. **3**B illustrates a process flow diagram for operating a tablet ultrasound system in accordance with preferred embodiments of the invention;

FIG. **3**C-**3**K illustrates details of touchscreen gestures to adjust beamforming and display operation;

FIGS. **4**A-**4**C illustrates exemplary subsets of touch controls that can be implemented on the medical ultrasound imaging system in accordance with preferred embodiments of the invention;

FIGS. **5**A and **5**B are exemplary representations of a liver with a cystic lesion on a touch screen display of the medical ultrasound imaging system in accordance with preferred embodiments of the invention;

FIGS. **5**C and **5**D are exemplary representations of the liver and cystic lesion on the touch screen display of FIGS. **5**A and **5**B, including a virtual window that corresponds to a magnified portion of the liver;

FIG. **6**A is an exemplary representation of an apical four (4) chamber view of a heart on the touch screen display of the medical ultrasound imaging system;

FIGS. **6**B-**6**E illustrates an exemplary manual tracing of an endocardial border of a left ventricle of the heart on the touch screen display of FIG. **6**A;

FIGS. **7**A-**7**C illustrates an exemplary measurement of the size of the cystic lesion on the liver within the virtual window of FIGS. **5**C and **5**D;

FIGS. **8**A-**8**C illustrates an exemplary caliper measurement of the cystic lesion on the liver within the virtual window of FIGS. **5**C and **5**D;

FIG. **9**A illustrates one of a plurality of transducer arrays attached to the processor housing;

FIG. **9**B shows a transducer attach sequence in accordance with exemplary embodiments;

FIG. **9**C shows a perspective view of a needle sensing positioning system with exemplary embodiments;

FIG. **9**D shows a perspective view of a needle guide with exemplary embodiments;

FIG. **9**E shows a perspective view of a needle sensing positioning system with exemplary embodiments;

FIG. **10**A shows a method of measuring heart wall motion;

FIG. **10**B shows a schematic block diagram for an integrated ultrasound probe with exemplary embodiments;

FIG. **10**C shows a schematic block diagram for an integrated ultrasound probe with exemplary embodiments;

FIG. **11** is a detailed schematic block diagram of an exemplary embodiment of an ultrasound engine (i.e., the front-end ultrasound specific circuitry) and an exemplary embodiment of a computer motherboard (i.e., the host computer) of the exemplary ultrasound device;

FIG. **12** depicts a schematic side view of a circuit board including a multi-chip module assembled in a vertically stacked configuration;

FIG. **13** is a flowchart of an exemplary method for fabricating a circuit board including a multi-chip module assembled in a vertically stacked configuration;

FIG. **14**A is a schematic side view of a multi-chip module including four vertically stacked dies in which the dies are spacedly separated from one another by passive silicon layers with a 2-in-1 dicing die attach film (D-DAF);

FIG. **14**B is a schematic side view of a multi-chip module including four vertically stacked dies in which the dies are spacedly separated from one another by DA film-based adhesives acting as die-to-die spacers;

FIG. **14**C is a schematic side view of a multi-chip module including four vertically stacked dies in which the dies are spacedly separated from one another by DA paste or film-based adhesives acting as die-to-die spacers;

FIG. **15** is a flowchart of another exemplary method of die-to-die stacking using (a) passive silicon layers with a 2-in-1 dicing die attach film (D-DAF), (b) DA paste, (c) thick DA-film, and (d) film-over wire (FOW) including a 2-in-1 D-DAF;

FIG. **16** is a schematic side view of a multi-chip module including an ultrasound transmit/receive IC chip, an amplifier IC chip and an ultrasound beamformer IC chip vertically integrated in a vertically stacked configuration;

FIG. **17** is a detailed schematic block diagram of an exemplary embodiment of an ultrasound engine (i.e., the front-end ultrasound specific circuitry) and an exemplary embodiment of a computer motherboard (i.e., the host computer) provided as a single board complete ultrasound system;

FIG. **18** is a perspective view of an exemplary portable ultrasound system provided in accordance with exemplary embodiments;

FIG. **19** illustrates an exemplary view of a main graphical user interface (GUI) rendered on a touch screen display of the exemplary portable ultrasound system of FIG. **18**;

FIG. **20** is a top view of the medical ultrasound imaging system in accordance with another preferred embodiment of the invention;

FIG. **21** illustrates a preferred cart system for a tablet ultrasound system in accordance with preferred embodiment 9 of the invention;

FIG. **22** illustrates preferred cart system for a modular ultrasound imaging system in accordance with preferred embodiments of the invention;

FIG. **23** illustrates preferred cart system for a modular ultrasound imaging system in accordance with preferred embodiments of the invention;

FIG. **24** illustrates preferred cart system for a modular ultrasound imaging system in accordance with preferred embodiments of the invention;

FIGS. **25**A-**25**B illustrate a multifunction docking base for tablet ultrasound device;

FIG. **26** illustrates a 2D imaging mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **27** illustrates a motion mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **28** illustrates a color Doppler mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **29** illustrates a pulsed-wave Doppler mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **30** illustrates a Triplex scan mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **31** illustrates a GUI Home Screen interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **32** illustrates a GUI Menu Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **33** illustrates a GUI Patient Data Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **34** illustrates a GUI Pre-sets Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **35** illustrates a GUI Review Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **36** illustrates a GUI Report Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIGS. **37**A-**37**C illustrates a GUI Setup Display Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIG. **38** illustrates a GUI Setup Store/Acquire Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention;

FIGS. **39**A-**39**C illustrate XY bi-plane probe comprising a two one-dimensional, ID multi-element arrays in accordance with a preferred embodiment of the invention;

FIG. **40** illustrates the operation of a bi-plane image forming xy-probe;

FIG. **41** illustrates the operation of a bi-plane image forming xy-probe;

FIG. **42** illustrates a high voltage driver circuit for a bi-plane image forming xy-probe;

FIGS. **43**A-**43**B illustrate simultaneous bi-plane evaluation of left ventricular condition; and

FIGS. **44**A-**44**B illustrate ejection fraction probe measurement techniques in accordance with preferred embodiments of the invention;

DETAILED DESCRIPTION

Systems and methods of medical ultrasound imaging are disclosed. The presently disclosed systems and methods of medical ultrasound imaging employ medical ultrasound imaging equipment that includes housing in a tablet form factor, and a touch screen display disposed on a front panel of the housing. The touch screen display includes a multi-touch touch screen that can recognize and distinguish one or more single, multiple, and/or simultaneous touches on a surface of the touch screen display, thereby allowing the use of gestures, ranging from simple single point gestures to complex multipoint gestures, as user inputs to the medical ultrasound imaging equipment. Further details regarding tablet ultrasound systems and operations are described in U.S. application Ser. No. 10/997,062 filed on Nov. 11, 2004, Ser. No. 10/386,360 filed Mar. 11, 2003 and U.S. Pat. No. 6,969,352, the entire contents of these patents and applications are incorporated herein by reference.

FIG. **1** depicts an illustrative embodiment of exemplary medical ultrasound imaging equipment **100**, in accordance with the present application. As shown in FIG. **1**, the medical ultrasound imaging equipment **100** includes a housing **102**, a touch screen display **104**, a computer having at least one processor and at least one memory implemented on a computer motherboard **106**, an ultrasound engine **108**, and a battery **110**. For example, the housing **102** can be implemented in a tablet form factor, or any other suitable form factor. The housing **102** has a front panel **101** and a rear panel **103**. The touch screen display **104** is disposed on the front panel **101** of the housing **102**, and includes a multi-touch LCD touch screen that can recognize and distinguish one or more multiple and/or simultaneous touches on a surface **105** of the touch screen display **104**. The computer motherboard **106**, the ultrasound engine **108**, and the battery **110** are operatively disposed within the housing **102**. The medical ultrasound imaging equipment **100** further includes a Firewire connection **112** (see also FIG. **2**A) operatively connected between the computer motherboard **106** and the ultrasound engine **108** within the housing **102**, and a probe connector **114** having a probe attach/detach lever **115** (see also FIGS. **2**A and **2**B) to facilitate the connection of at least one ultrasound probe/transducer. The transducer probe housing can include circuit components including a transducer array, transmit and receive circuitry, as well as beamformer and beamformer control circuits in certain preferred embodiments. In addition, the medical ultrasound imaging equipment **100** has one or more I/O port connectors **116** (see FIG. **2**A), which can include, but are not limited to, one or more USB connectors, one or more SD cards, one or more network ports, one or more mini display ports, and a DC power input.

In an exemplary mode of operation, medical personnel (also referred to herein as the "user" or "users") can employ simple single point gestures and/or more complex multipoint gestures as user inputs to the multi-touch LCD touch screen of the touch screen display **104** for controlling one or more operational modes and/or functions of the medical ultrasound imaging equipment **100**. Such a gesture is defined herein as a movement, a stroke, or a position of at least one finger, a stylus, and/or a palm on the surface **105** of the touch screen display **104**. For example, such single point/multipoint gestures can include static or dynamic gestures, continuous or segmented gestures, and/or any other suitable gestures. A single point gesture is defined herein as a gesture that can be performed with a single touch contact point on the touch screen display **104** by a single finger, a stylus, or a palm. A multipoint gesture is defined herein as a gesture that can be performed with multiple touch contact points on the touch screen display **104** by multiple fingers, or any suitable combination of at least one finger, a stylus, and a palm. A static gesture is defined herein as a gesture that does not involve the movement of at least one finger, a stylus, or a palm on the surface **105** of the touch screen display **104**. A dynamic gesture is defined herein as a gesture that involves the movement of at least one finger, a stylus, or a palm, such as the movement caused by dragging one or more fingers across the surface **105** of the touch screen display **104**. A continuous gesture is defined herein as a gesture that can be performed in a single movement or stroke of at least one finger, a stylus, or a palm on the surface **105** of the touch screen display **104**. A segmented gesture is defined herein as a gesture that can be performed in multiple movements or stokes of at least one finger, a stylus, or a palm on the surface **105** of the touch screen display **104**.

Such single point/multipoint gestures performed on the surface **105** of the touch screen display **104** can correspond to single or multipoint touch events, which are mapped to one or more predetermined operations that can be performed by the computer and/or the ultrasound engine **108**. Users can make such single point/multipoint gestures by various single finger, multi-finger, stylus, and/or palm motions on the surface **105** of the touch screen display **104**. The multi-touch LCD touch screen receives the single point/multipoint gestures as user inputs, and provides the user inputs to the processor, which executes program instructions stored in the memory to carry out the predetermined operations associated with the single point/multipoint gestures, at least at some times, in conjunction with the ultrasound engine **108**. As shown in FIG. **3**AA-**3**AL, such single point/multipoint gestures on the surface **105** of the touch screen display **104** can include, but are not limited to, a tap gesture **302**, a pinch gesture **304**, a flick gesture **306**, **314**, a rotate gesture **308**, **316**, a double tap gesture **310**, a spread gesture **312**, a drag gesture **318**, a press gesture **320**, a press and drag gesture **322**, and/or a palm gesture **324**. For example, such single point/multipoint gestures can be stored in at least one gesture library in the memory implemented on the computer motherboard **106**. The computer program operative to control system operations can be stored on a computer readable medium and can optionally be implemented using a touch processor connected to an image processor and a control processor connected to the system beamformer. Thus beamformer delays associated with both transmission and reception can be adjusted in response to both static and moving touch gestures.

In accordance with the illustrative embodiment of FIG. **1**, at least one flick gesture **306** or **314** may be employed by a user of the medical ultrasound imaging equipment **100** to control the depth of tissue penetration of ultrasound waves generated by the ultrasound probe/transducer. For example, a dynamic, continuous, flick gesture **306** or **314** in the "up" direction, or any other suitable direction, on the surface **105** of the touch screen display **104** can increase the penetration depth by one (1) centimeter, or any other suitable amount. Further, a dynamic, continuous, flick gesture **306** or **314** in the "down" direction, or any other suitable direction, on the surface **105** of the touch screen display **104** can decrease the penetration depth by one (1) centimeter, or any other suitable amount. Moreover, a dynamic, continuous, drag gesture **318** in the "up" or "down" direction, or any other suitable direction, on the surface **105** of the touch screen display **104** can increase or decrease the penetration depth in multiple centimeters, or any other suitable amounts.

Additional operational modes and/or functions controlled by specific single point/multipoint gestures on the surface **105** of the touch screen display **104** can include, but are not limited to, freeze/store operations, 2-dimensional mode operations, gain control, color control, split screen control, PW imaging control, cine/time-series image clip scrolling control, zoom and pan control, full screen display, Doppler and 2-dimensional beam steering control, and/or body marking control. At least some of the operational modes and/or functions of the medical ultrasound imaging equipment **100** can be controlled by one or more touch controls implemented on the touch screen display **104**. Further, users can provide one or more specific single point/multipoint gestures as user inputs for specifying at least one selected subset of the touch controls to be implemented, as required and/or desired, on the touch screen display **104**.

Shown in FIG. **3**B is a process sequence in which ultrasound beamforming and imaging operations **340** are controlled in response to touch gestures entered on a touchscreen. Various static and moving touch gestures have been programmed into the system such that the data processor operable to control beamforming and image processing operations **342** within the tablet device. A user can select **344** a first display operation having a first plurality of touch gestures associated therewith. Using a static or moving gesture the user can perform one of the plurality of gestures operable to control the imaging operation and can specifically select one of a plurality of gestures that can adjust beamforming parameters **346** being used to generate image data associated with the first display operation. The displayed image is updated and displayed **348** response to the updated beamforming procedure. The user can further elect to perform a different gesture having a different velocity characteristic (direction or speed or both) to adjust **350** a second characteristic of the first ultrasound display operation. The displayed image is then updated **352** based on the second gesture, which can modify imaging processing parameters or beamforming parameters. Examples of this process are described in further detail herein where changes in velocity and direction of different gestures can be associated with distinct imaging parameters of a selected display operation.

Ultrasound images of flow or tissue movement, whether color flow or spectral Doppler, are essentially obtained from measurements of movement. In ultrasound scanners, a series of pulses is transmitted to detect movement of blood. Echoes from stationary targets are the same from pulse to pulse. Echoes from moving scatterers exhibit slight differences in the time for the signal to be returned to the scanner.

As can be seen from FIG. **3**C-**3**H, there has to be motion in the direction of the beam; if the flow is perpendicular to the beam, there is no relative motion from pulse to pulse receive, there is no flow detected. These differences can be measured as a direct time difference or, more usually, in terms of a phase shift from which the 'Doppler frequency' is obtained. They are then processed to produce either a color flow display or a Doppler sonogram. In FIG. **3**C-**3**D, the flow direction is perpendicular to the beam direction, no flow is measured by Pulse Wave spectral Doppler. In FIG. **3**G-**3**H when the ultrasound beam is steered to an angle that is better aligned to the flow, a weak flow is shown in the color flow map, and in addition flow is measured by Pulse Wave Doppler. In FIG. **3**H, when the ultrasound beam is steered to an angle much better aligned to the flow direction in response to a moving, the color flow map is stronger, in addition when the correction angle of the PWD is placed aligned to the flow, a strong flow is measured by the PWD.

In this tablet ultrasound system, an ROI, region of interest, is also used to define the direction in response to a moving gesture of the ultrasound transmit beam. A liver image with a branch of renal flow in color flow mode is shown in FIG. **3**I since the ROI is straight down from the transducer, the flow direction is almost normal to the ultrasound beam, so very week renal flow is detected. Hence, the color flow mode is used to image a renal flow in liver. As can be seen, the beam is almost normal to the flow and very weak flow is detected. A flick gesture with the finger outside of the ROI is used to steer the beam. As can be seen in FIG. **3**J, the ROI is steered by resetting beamforming parameters so that the beam direction is more aligned to the flow direction, a much stronger flow within the ROI is detected. In FIG. 3J, a flick gesture with the finger outside of the ROI is used to steer the ultrasound beam into the direction more aligned to the flow direction. Stronger flow within the ROI can be seen. A panning gesture with the finger inside the ROI will move the ROI box into a position that covers the entire renal region, i.e., panning allows a translation movement of the ROI box such that the box covers the entire target area.

FIG. **3**K demonstrates a panning gesture. With the finger inside the ROI, it can move the ROI box to any place within the image plane. In the above embodiment, it is easy to differentiate a "flick" gesture with a finger outside an "ROI" box is intended for steering a beam, and a "drag-and-move, panning" gesture with a finger inside the "ROI" is intended for moving the ROI box. However, there are applications in which no ROI as a reference region, then it is easy to see that it is difficult to differentiate a "flick" or a "panning" gesture, in this case, the touch-screen program needs to track the initial velocity or acceleration of the finger to determine it is a "flick" gesture or a "drag-and-move" gesture. Thus, the touch engine that receives data from the touchscreen sensor device is programmed to discriminate between velocity thresholds that indicate different gestures. Thus, the time, speed and direction associated with different moving gestures can have preset thresholds. Two and three finger static and moving gestures can have separate thresholds to differentiate these control operations. Note that preset displayed icons or virtual buttons can have distinct static pressure or time duration thresholds. When operated in full screen mode, the touchscreen processor, which is preferably operating on the systems central processing unit that performs other imaging operations such as scan conversion, switches off the static icons.

FIGS. **4**A-**4**C depict exemplary subsets **402**, **404**, **406** of touch controls that can be implemented by users of the medical ultrasound imaging equipment **100** on the touch screen display **104**. It is noted that any other suitable subset(s) of touch controls can be implemented, as required and/or desired, on the touch screen display **104**. As shown in FIG. **4**A, the subset **402** includes a touch control **408** for performing 2-dimensional (2D) mode operations, a touch control **410** for performing gain control operations, a touch control **412** for performing color control operations, and a touch control **414** for performing image/clip freeze/store operations. For example, a user can employ the press gesture **320** to actuate the touch control **408**, returning the medical ultrasound imaging equipment **100** to 2D mode. Further, the user can employ the press gesture **320** against one side of the touch control **410** to decrease a gain level, and employ the press gesture **320** against another side of the touch control **410** to increase the gain level. Moreover, the user can employ the drag gesture **318** on the touch control **412** to identify ranges of densities on a 2D image, using a predetermined color code. In addition, the user can employ the press gesture **320** to actuate the touch control **414** to freeze/store a still image or to acquire a cine image clip.

As shown in FIG. **4**B, the subset **404** includes a touch control **416** for performing split screen control operations, a touch control **418** for performing PW imaging control operations, a touch control **420** for performing Doppler and 2-dimensional beam steering control operations, and a touch control **422** for performing annotation operations. For example, a user can employ the press gesture **320** against the touch control **416**, allowing the user to toggle between opposing sides of the split touch screen display **104** by alternately employing the tap gesture **302** on each side of the split screen. Further, the user can employ the press gesture **320** to actuate the touch control **418** and enter the PW mode, which allows (1) user control of the angle correction, (2) movement (e.g., "up" or "down") of a baseline that can be displayed on the touch screen display **104** by employing the press and drag gesture **322**, and/or (3) an increase or a decrease of scale by employing the tap gesture **302** on a scale bar that can be displayed on the touch screen display **104**. Moreover, the user can employ the press gesture **320** against one side of the touch control **420** to perform 2D beam steering to the "left" or any other suitable direction in increments of five (5) or any other suitable increment, and employ the press gesture **320** against another side of the touch control **420** to perform 2D beam steering to the "right" or any other suitable direction in increments of five (5) or any other suitable increment. In addition, the user can employ the tap gesture **302** on the touch control **422**, allowing the user to enter annotation information via a pop-up keyboard that can be displayed on the touch screen display **104**.

As shown in FIG. **4**C, the subset **406** includes a touch control **424** for performing dynamic range operations, a touch control **426** for performing Teravision™ software operations, a touch control **428** for performing map operations, and a touch control **430** for performing needle guide operations. For example, a user can employ the press gesture **320** and/or the press and drag gesture **322** against the touch control **424** to control or set the dynamic range. Further, the user can employ the tap gesture **302** on the touch control **426** to choose a desired level of the Teravision™ software to be executed from the memory by the processor on the computer motherboard **106**. Moreover, the user can employ the tap gesture **302** on the touch control **428** to perform a desired map operation. In addition, the user can employ the press gesture **320** against the touch control **430** to perform a desired needle guide operation.

In accordance with the present application, various measurements and/or tracings of objects (such as organs, tissues, etc.) displayed as ultrasound images on the touch screen display **104** of the medical ultrasound imaging equipment **100** (see FIG. **1**) can be performed, using single point/multipoint gestures on the surface **105** of the touch screen display **104**. The user can perform such measurements and/or tracings of objects directly on an original ultrasound image of the displayed object, on a magnified version of the ultrasound image of the displayed object, and/or on a magnified portion of the ultrasound image within a virtual window **506** (see FIGS. **5**C and **5**D) on the touch screen display **104**.

FIGS. **5**A and **5**B depict an original ultrasound image of an exemplary object, namely, a liver **502** with a cystic lesion **504**, displayed on the touch screen display **104** of the medical ultrasound imaging equipment **100** (see FIG. **1**). It is noted that such an ultrasound image can be generated by the medical ultrasound imaging equipment **100** in response to penetration of the liver tissue by ultrasound waves generated by an ultrasound probe/transducer operatively connected to the equipment **100**. Measurements and/or tracings of the liver **502** with the cystic lesion **504** can be performed directly on the original ultrasound image displayed on the touch screen display **104** (see FIGS. **5**A and **5**B), or on a magnified version of the ultrasound image. For example, the user can obtain such a magnified version of the ultrasound image using a spread gesture (see, e.g., the spread gesture **312**; FIG. **3**) by placing two (2) fingers on the surface **105** of the touch screen display **104**, and spreading them apart to magnify the original ultrasound image. Such measurements and/or tracings of the liver **502** and cystic lesion **504** can also be performed on a magnified portion of the ultrasound image within the virtual window **506** (see FIGS. **5**C and **5**D) on the touch screen display **104**.

For example, using his or her finger (see, e.g., a finger **508**; FIGS. **5**A-**5**D), the user can obtain the virtual window **506** by employing a press gesture (see, e.g., the press gesture **320**; FIG. **3**) against the surface **105** of the touch screen display **104** (see FIG. **5**B) in the vicinity of a region of interest, such as the region corresponding to the cystic lesion **504**. In response to the press gesture, the virtual window **506** (see FIGS. **5**C and **5**D) is displayed on the touch screen display **104**, possibly at least partially superimposed on the original ultrasound image, thereby providing the user with a view of a magnified portion of the liver **502** in the vicinity of the cystic lesion **504**. For example, the virtual window **506** of FIG. **5**C can provide a view of a magnified portion of the ultrasound image of the cystic lesion **504**, which is covered by the finger **508** pressed against the surface **105** of the touch screen display **104**. To re-position the magnified cystic lesion **504** within the virtual window **506**, the user can employ a press and drag gesture (see, e.g., the press and drag gesture **322**; FIG. **3**) against the surface **105** of the touch screen display **104** (see FIG. **5**D), thereby moving the image of the cystic lesion **504** to a desired position within the virtual window **506**. In one embodiment, the medical ultrasound imaging equipment **100** can be configured to allow the user to select a level of magnification within the virtual window **506** to be 2 times larger, 4 times larger, or any other suitable number of times larger than the original ultrasound image. The user can remove the virtual window **506** from the touch screen display **104** by lifting his or her finger (see, e.g., the finger **508**; FIGS. **5**A-**5**D) from the surface **105** of the touch screen display **104**.

FIG. **6**A depicts an ultrasound image of another exemplary object, namely, an apical four (4) chamber view of a heart **602**, displayed on the touch screen display **104** of the medical ultrasound imaging equipment **100** (see FIG. **1**). It is noted that such an ultrasound image can be generated by the medical ultrasound imaging equipment **100** in response to penetration of the heart tissue by ultrasound waves generated by an ultrasound probe/transducer operatively connected to the equipment **100**. Measurements and/or tracings of the heart **602** can be performed directly on the original ultrasound image displayed on the touch screen display **104** (see FIGS. **6**A-**6**E), or on a magnified version of the ultrasound image. For example, using his or her fingers (see, e.g., fingers **610**, **612**; FIGS. **6**B-**6**E), the user can perform a manual tracing of an endocardial border **604** (see FIG. **6**B) of a left ventricle **606** (see FIGS. **6**B-**6**E) of the heart **602** by employing one or more multi-finger gestures on the surface **105** of the touch screen display **104**. In one embodiment, using his or her fingers (see, e.g., the fingers **610, 612**; FIGS. **6**B-**6**E), the user can obtain a cursor **607** (see FIG. **6**B) by employing a double tap gesture (see, e.g., the double tap gesture **310**; FIG. **3**AA-**3**AL) on the surface **105** of the touch screen display **104**, and can move the cursor **607** by employing a drag gesture (see, e.g., the drag gesture **318**; FIG. **3**AA-**3**AL) using one finger, such as the finger **610**, thereby moving the cursor **607** to a desired location on the touch screen display **104**. The systems and methods described herein can be used for the quantitative measurement of heart wall motion and specifically for the measurement of ventricular dysynchrony as described in detail in U.S. application Ser. No. 10/817,316 filed on Apr. 2, 2004, the entire contents of which is incorporated herein by reference.

Once the cursor **607** is at the desired location on the touch screen display **104**, as determined by the location of the finger **610**, the user can fix the cursor **607** at that location by employing a tap gesture (see, e.g., the tap gesture **302**; see FIG. **3**) using another finger, such as the finger **612**. To perform a manual tracing of the endocardial border **604** (see FIG. **6**B), the user can employ a press and drag gesture (see, e.g., the press and drag gesture **322**; FIG. **3**) using the finger **610**, as illustrated in FIGS. **6**C and **6**D. Such a manual tracing of the endocardial border **604** can be highlighted on the touch screen display **104** in any suitable fashion, such as by a dashed line **608** (see FIGS. **6**C-**6**E). The manual tracing of the endocardial border **604** can continue until the finger **610** arrives at any suitable location on the touch screen display **104**, or until the finger **610** returns to the location of the cursor **607**, as illustrated in FIG. **6**E. Once the finger **610** is at the location of the cursor **607**, or at any other suitable location, the user can complete the manual tracing operation by employing a tap gesture (see, e.g., the tap gesture **302**; see FIG. **3**) using the finger **612**. It is noted that such a manual tracing operation can be employed to trace any other suitable feature(s) and/or waveform(s), such as a pulsed wave Doppler (PWD) waveform. In one embodiment, the medical ultrasound imaging equipment **100** can be configured to perform any suitable calculation(s) and/or measurement(s) relating to such feature(s) and/or waveform(s), based at least in part on a manual tracing(s) of the respective feature(s)/waveform(s).

As described above, the user can perform measurements and/or tracings of objects on a magnified portion of an original ultrasound image of a displayed object within a virtual window on the touch screen display **104**. FIGS. **7**A-**7**C depict an original ultrasound image of an exemplary object, namely, a liver **702** with a cystic lesion **704**, displayed on the touch screen display **104** of the medical ultrasound imaging equipment **100** (see FIG. **1**). FIGS. **7**A-**7**C further depict a virtual window **706** that provides a view of a magnified portion of the ultrasound image of the cystic lesion **704**, which is covered by one of the user's fingers, such as a finger **710**, pressed against the surface **105** of the touch screen display **104**. Using his or her fingers (see, e.g., fingers **710**, **712**; FIGS. **7**A-**7**C), the user can perform a size measurement of the cystic lesion **704** within the virtual window **706** by employing one or more multi-finger gestures on the surface **105** of the touch screen display **104**.

For example, using his or her fingers (see, e.g., the fingers **710**, **712**; FIGS. **7**A-**7**C), the user can obtain a first cursor **707** (see FIGS. **7**B, **7**C) by employing a double tap gesture (see, e.g., the double tap gesture **310**; FIG. **3**) on the surface **105**, and can move the first cursor **707** by employing a drag gesture (see, e.g., the drag gesture **318**; FIG. **3**) using one finger, such as the finger **710**, thereby moving the first cursor **707** to a desired location. Once the first cursor **707** is at the desired location, as determined by the location of the finger **710**, the user can fix the first cursor **707** at that location by employing a tap gesture (see, e.g., the tap gesture **302**; see FIG. **3**) using another finger, such as the finger **712**. Similarly, the user can obtain a second cursor **709** (see FIG. **7**C) by employing a double tap gesture (see, e.g., the double tap gesture **310**; FIG. **3**) on the surface **105**, and can move the second cursor **709** by employing a drag gesture (see, e.g., the drag gesture **318**; FIG. **3**) using the finger **710**, thereby moving the second cursor **709** to a desired location. Once the second cursor **709** is at the desired location, as determined by the location of the finger **710**, the user can fix the second cursor **709** at that location by employing a tap gesture (see, e.g., the tap gesture **302**; see FIG. **3**) using the finger **712**. In one embodiment, the medical ultrasound imaging equipment **100** can be configured to perform any suitable size calculation(s) and/or measurement(s) relating to the cystic lesion **704**, based at least in part on the locations of the first and second cursors **707**, **709**.

FIGS. **8**A-**8**C depict an original ultrasound image of an exemplary object, namely, a liver **802** with a cystic lesion **804**, displayed on the touch screen display **104** of the medical ultrasound imaging equipment **100** (see FIG. **1**). FIGS. **8***a*-**8***c* further depict a virtual window **806** that provides a view of a magnified portion of the ultrasound image of the cystic lesion **804**, which is covered by one of the user's fingers, such as a finger **810**, pressed against the surface **105** of the touch screen display **104**. Using his or her fingers (see, e.g., fingers **810**, **812**; FIGS. **8**A-**8**C), the user can perform a caliper measurement of the cystic lesion **804** within the virtual window **806** by employing one or more multi-finger gestures on the surface **105** of the touch screen display **104**.

For example, using his or her fingers (see, e.g., the fingers **810**, **812**; FIGS. **8**A-**8**C), the user can obtain a first cursor **807** (see FIGS. **8**B, **8**C) by employing a double tap gesture (see, e.g., the double tap gesture **310**; FIG. **3**) on the surface **105**, and can move the cursor **807** by employing a drag gesture (see, e.g., the drag gesture **318**; FIG. **3**) using one finger, such as the finger **810**, thereby moving the cursor **807** to a desired location. Once the cursor **807** is at the desired location, as determined by the location of the finger **810**, the user can fix the cursor **807** at that location by employing a tap gesture (see, e.g., the tap gesture **302**; see FIG. **3**) using another finger, such as the finger **812**. The user can then employ a press and drag gesture (see, e.g., the press and drag gesture **322**; FIG. **3**) to obtain a connecting line **811** (see FIGS. **8**B, **8**C), and to extend the connecting line **811** from the first cursor **807** across the cystic lesion **804** to a desired location on another side of the cystic lesion **804**. Once the connecting line **811** is extended across the cystic lesion **804** to the desired location on the other side of the cystic lesion **804**, the user can employ a tap gesture (see, e.g., the tap gesture **302**; see FIG. **3**) using the finger **812** to obtain and fix a second cursor **809** (see FIG. **8**C) at that desired location. In one embodiment, the medical ultrasound imaging equipment **100** can be configured to perform any suitable caliper calculation(s) and/or measurement(s) relating to the cystic lesion **804**, based at least in part on the connecting line **811** extending between the locations of the first and second cursors **807**, **809**.

FIG. **9**A shows a system **140** in which a transducer housing **150** with an array of transducer elements **152** can be attached at connector **114** to housing **102**. Each probe **150** can have a probe identification circuit **154** that uniquely identifies the probe that is attached. When the user inserts a different probe with a different array, the system identifies the probe operating parameters. Note that preferred embodiments can include a display **104** having a touch sensor **107** which can be connected to a touch processor **109** that analyzes touchscreen data from the sensor **107** and transmits commands to both image processing operations and to a beamformer control processor (**1116**, **1124**). In a preferred embodiment, the touch processor can include a computer readable medium that stores instructions to operate an ultrasound touchscreen engine that is operable to control display and imaging operations described herein.

FIG. **9**B shows a software flowchart **900** of a typical transducer management module **902** within the ultrasound application program. When a TRANSDUCER ATTACH **904** event is detected, the Transducer Management Software Module **902** first reads the Transducer type ID **906** and hardware revision information from the IDENTIFICATION Segment. The information is used to fetch the particular set of transducer profile data **908** from the hard disk and load it into the memory of the application program. The software then reads the adjustment data from the FACTORY Segment **910** and applies the adjustments to the profile data just loaded into memory **912**. The software module then sends a TRANSDUCER ATTACH Message **914** to the main ultrasound application program, which uses the transducer profile already loaded. After acknowledgment **916**, an ultrasound imaging sequence is performed and the USAGE segment is updated **918**. The Transducer Management Software Module then waits for either a TRANSDUCER DETACH event **920**, or the elapse of 5 minutes. If a TRANSDUCER DETACH event is detected **921**, a message **924** is sent and acknowledged **926**, the transducer profile data set is removed **928** from memory and the module goes back to wait for another TRANSDUCER ATTACH event. If a 5 minutes time period expires without detecting a TRANSDUCER DETACH event, the software module increments a Cumulative Usage Counter in the USAGE Segment **922**, and waits for another 5 minutes period or a TRANSDUCER DETACH event. The cumulative usage is recorded in memory for maintenance and replacement records.

There are many types of ultrasound transducers. They differ by geometry, number of elements, and frequency response. For example, a linear array with center frequency of 10 to 15 MHz is better suited for breast imaging, and a curved array with center frequency of 3 to 5 MHz is better suited for abdominal imaging.

It is often necessary to use different types of transducers for the same or different ultrasound scanning sessions. For ultrasound systems with only one transducer connection, the operator will change the transducer prior to the start of a new scanning session.

In some applications, it is necessary to switch among different types of transducers during one ultrasound scanning session. In this case, it is more convenient to have multiple transducers connected to the same ultrasound system, and the operator can quickly switch among these connected transducers by hitting a button on the operator console, without having to physically detach and re-attach the transducers, which takes a longer time. Preferred embodiments of the invention can include a multiplexor within the tablet housing that can select between a plurality of probe connector ports within the tablet housing, or alternatively, the tablet housing can be connected to an external multiplexor that can be mounted on a cart as described herein.

FIG. **9**C is a perspective view of an exemplary needle sensing positioning system using ultrasound transducers without the requirement of any active electronics in the sensor assembly. The sensor transducer may include a passive ultrasound transducer element. The elements may be used in a similar way as a typical transducer probe, utilizing the ultrasound engine electronics. The system **958** includes the addition of ultrasound transducer elements **960**, added to a needle guide **962**, that is represented in FIG. **9**C but that may be any suitable form factor. The ultrasound transducer element **960**, and needle guide **962**, may be mounted using a needle guide mounting bracket **966**, to an ultrasound transducer probe acoustic handle or an ultrasound imagining probe assembly **970**. The needle with a disc mounted on the exposed end, the ultrasound reflector disc **964**, is reflective to ultrasonic waves.

The ultrasound transducer element **960**, on the needle guide **962**, may be connected to the ultrasound engine. The connection may be made through a separate cable to a dedicated probe connector on the engine, similar to a sharing the pencil CW probe connector. In an alternate embodiment, a small short cable may be plugged into the larger image transducer probe handle or a split cable connecting to the same probe connector at the engine. In another alternate embodiment the connection may be made via an electrical connector between the image probe handle and the needle guide without a cable in between. In an alternate embodiment the ultrasound transducer elements on the needle guide may be connected to the ultrasound engine by enclosing the needle guide and transducer elements in the same mechanical enclosure of the imagining probe handle.

FIG. **9**D is a perspective view of a needle guide **962**, positioned with transducer elements **960** and the ultrasound reflector disc **964**. The position of the reflector disc **964** is located by transmitting ultrasonic wave **972**, from the transducer element **960** on the needle guide **962**. The ultrasound wave **972** travels through the air towards reflector disc **964** and is reflected by the reflector disc **964**. The reflected ultrasound wave **974**, reaches the transducer element **960** on the needle guide **962**. The distance **976**, between the reflector disc **964**, and the transducer element **960** is calculated from the time elapsed and the speed of sound in the air.

FIG. **9**E is a perspective view of an alternate embodiment of the exemplary needle sensing positioning system using ultrasound transducers without the requirement of any active electronics in the sensor assembly. The sensor transducer may include a passive ultrasound transducer element. The elements may be used in a similar way as a typical transducer probe, utilizing the ultrasound engine electronics.

The system **986** includes needle guide **962** that may be mounted to a needle guide mounting bracket **966** that may be coupled to an ultrasound imaging probe assembly for imaging the patient's body **982**, or alternative suitable form factors. The ultrasound reflector disc **964** may be mounted at the exposed end of the needle **956**. In this embodiment a linear ultrasound acoustic array **978**, is mounted parallel to the direction of movement of the needle **956**. The linear ultrasound acoustic array **978** includes an ultrasound transducer array **980** positioned parallel to the needle **956**. In this embodiment an ultrasound imagining probe assembly **982**, is positioned for imagining the patient body. The ultrasound imaging probe assembly for imaging the patient body **982** is configured with an ultrasound transducer array **984**.

In this embodiment, the position of the ultrasound reflector disc **964** can be detected by using the ultrasound transducer array **980** coupled to an ultrasound imaging probe assembly for imaging **978**. The position of the reflector disc **964** is located by transmitting ultrasonic wave **972**, from the transducer element **980** on the ultrasound imaging probe assembly for imaging **978**. The ultrasound wave **972** travels through the air towards reflector disc **964** and is reflected by the reflector disc **964**. The reflected ultrasound wave **974**, reaches the transducer element **980** on the ultrasound imaging probe assembly for imaging **978**. The distance **976**, between the reflector disc **964**, and the transducer element **980** is calculated from the time elapsed and the speed of sound in the air. In an alternate embodiment an alternate algorithm may be used to sequentially scan the polarity of elements in the transducer array and analyze the reflections produced per transducer array element. In an alternate embodiment a plurality of scans may occur prior to forming an ultrasound image.

FIG. **10**A illustrates an exemplary method for monitoring the synchrony of a heart in accordance with exemplary embodiments. In the method, a reference template is loaded into memory and used to guide a user in identifying an imaging plane (per step **930**). Next a user identifies a desired imaging plane (per step **932**). Typically an apical 4-chamber view of the heart is used; however, other views may be used without departing from the spirit of the invention.

At times, identification of endocardial borders may be difficult, and when such difficulties are encountered tissue Doppler imaging of the same view may be employed (per step **934**). A reference template for identifying the septal and lateral free wall is provided (per step **936**). Next, standard tissue Doppler imaging (TDI) with pre-set velocity scales of, say, ±30 cm/sec may be used (per step **938**).

Then, a reference of the desired triplex image may be provided (per step **940**). Either B-mode or TDI may be used to guide the range gate (per step **942**). B-mode can be used for guiding the range gate (per step **944**) or TDI for guiding the range gate (per step **946**). Using TDI or B-mode for guiding the range gate also allows the use of a direction correction angle for allowing the Spectral Doppler to display the radial mean velocity of the septal wall. A first pulsed-wave spectral Doppler is then used to measure the septal wall mean velocity using duplex or triplex mode (per step **948**). The software used to process the data and calculate dysychrony can utilize a location (e.g. a center point) to automatically set an angle between dated locations on a heart wall to assist in simplifying the setting of parameters.

A second range-gate position is also guided using a duplex image or a TDI (per step **950**), and a directional correction angle may be used if desired. After step **950**, the mean velocity of the septal wall and lateral free wall are being tracked by the system. Time integration of the Spectral Doppler mean velocities **952** at regions of interest (e.g., the septum wall and the left ventricular free wall) then provides the displacement of the septal and left free wall, respectively.

The above method steps may be utilized in conjunction with a high pass filtering means, analog or digital, known in the relevant arts for removing any baseline disturbance present in collected signals. In addition, the disclosed method employs multiple simultaneous PW Spectral Doppler lines for tracking movement of the interventricular septum and the left ventricular fee wall. In additional, a multiple gate structure may be employed along each spectral line, thus allowing quantitative measurement of regional wall motion. Averaging over multiple gates may allow measurement of global wall movement.

FIG. **10**B is a detailed schematic block diagram for an exemplary embodiment of the integrated ultrasound probe **1040** can be connected to any PC **1010** through an Interface unit **1020**. The ultra sound probe **1040** is configured to transmit ultrasound waves to and reduce reflected ultrasound waves from on ore more image targets **1064**. The transducer **1040** can be coupled to the interface unit **1020** using one or more cables **1066**, **1068**. The interface unit **1020** can be positioned between the integrated ultrasound probe **1040** and the host computer **1010**. The two stage beam forming system **1040** and **1020** can be connected to any PC through a USB connection **1022**, **1012**.

The ultrasound probe **1040**, can include sub-arrays/apertures **1052** consisting of neighboring elements with an aperture smaller than that of the whole array. Returned echoes are received by the 1D transducer array **1062** and transmitted to the controller **1044**. The controller initiates formation of a coarse beam by transmitting the signals to memory **1058**, **1046**. The memory **1058**, **1046** transmits a signal to a transmit Driver 1 **1050**, and Transmit Driver m **1054**. Transmit Driver 1 **1050** and Transmit Driver m **1054** then send the signal to mux1 **1048** and mux m **1056**, respectively. The signal is transmitted to sub-array beamformer 1 **1052** and sub-array beamformer n **1060**.

The outputs of each coarse beam forming operation can include further processing through a second stage beam forming in the interface unit **1020** to convert the beam forming output to digital representation. The coarse beam forming operations can be coherently summed to form a fine beam output for the array. The signals can be transmitted from the ultrasound probe **1040** sub-array beam former 1 **1052** and sub-array beam former n **1060** to the A/D convertors **1030** and **1028** within the interface unit **1020**. Within the interface unit **1020** there are A/D converters **1028**, **1030** for converting the first stage beam forming output to digital representation. The digital conversion can be received from the A/D convertors **1030**, **1028** by a customer ASIC such as a FPGA **1026** to complete the second stage beam forming. The FPGA Digital beam forming **1026** can transmit information to the system controller **1024**. The system controller can transmit information to a memory **1032** which may send a signal back to the FPGA Digital Beam forming **1026**. Alternatively, the system controller **1024** may transmit information to the custom USB3 Chipset **1022**. The USB3 Chipset **1022** may then transmit information to a DC-DC convertor **1034**. In turn, the DC-DC convertor **1034** may transmit power from the interface unit **1020** to the ultrasound probe **1040**. Within the ultrasound probe **1040** a power supply **1042** may receive the power signal and interface with the transmit driver 1 **1050** to provide the power to the front end integration probe.

The Interface unit **1020** custom or USB3 Chipset **1022** may be used to provide a communication link between the interface unit **10220** and the host computer **1010**. The custom or USB3 Chipset **1022** transmits a signal to the host computer's **1010** custom or USB3 Chipset **1012**. The custom or the USB3 Chipset **1012** then interfaces with the microprocessor **1014**. The microprocessor **1014** then may display information or send information to a device **1075**.

In an alternate embodiment, a narrow band beamformer can be used. For example, an individual analog phase shifter is applied to each of the received echoes. The phase shifted outputs within each sub-array are then summed to form a coarse beam. The A/D converts can be used to digitize each of the coarse beams; a digital beam former is then used to form the fine beam.

In another embodiment, forming a 64 element linear array may use eight adjacent elements to form a coarse beam output. Such arrangement may utilize eight output analog cables connecting the outputs of the integrated probe to the interface units. The coarse beams may be sent through the cable to the corresponding A/D convertors located in the interface unit. The digital delay is used to form a fine beam output. Eight A/D convertors may be required to form the digital representation.

In another embodiment, forming a 128 element array may use sixteen sub-array beam forming circuits. Each circuit may form a coarse beam from an adjacent eight element array provided in the first stage output to the interface unit. Such arrangement may utilize sixteen output analog cables connecting the outputs of the integrated probe to the interface units to digitize the output. A PC microprocessor or a DSP may be used to perform the down conversion, basebanding, scan conversion and post image processing functions. The microprocessor or DSP can also be used to perform all the Doppler processing functions.

FIG. **10**C is a detailed schematic block diagram for an exemplary embodiment of the integrated ultrasound probe **1040** with the first sub array beamforming circuit, and the second stage beamforming circuits are integrated inside the host computer **1082**. The back end computer with the second stage beamforming circuit may be a PDA, tablet or mobile device housing. The ultra sound probe **1040** is configured to transmit ultrasound waves to and reduce reflected ultrasound waves from on ore more image targets **1064**. The transducer **1040** is coupled to the host computer **1082** using one or more cables **1066**, **1068**. Note that A/D circuit elements can also be placed in the transducer probe housing.

The ultrasound probe **1040** includes subarray/apertures **1052** consisting of neighboring elements with an aperture smaller than that of the whole array. Returned echoes are received by the 1D transducer array **1062** and transmitted to the controller **1044**. The controller initiates formation of a coarse beam by transmitting the signals to memory **1058**, **1046**. The memory **1058**, **1046** transmits a signal to a transmit Driver 1 **1050**, and Transmit Driver m **1054**. Transmit Driver 1 **1050** and Transmit Driver m **1054** then send the signal to mux 1 **1048** and mux m **1056**, respectively. The signal is transmitted to subarray beamformer 1 **1052** and subarray beamformer n **1060**.

The outputs of each coarse beam forming operation then go through a second stage beam forming in the interface unit **1020** to convert the beam forming output to digital representation. The coarse beamforming operations are coherently summed to form a fine beam output for the array. The signals are transmitted from the ultrasound probe **1040** subarray beamformer 1 **1052** and subarray beamformer n **1060** to the A/D convertors **1030** and **1028** within the host computer **1082**. Within the host computer **1082** there are A/D converters **1028**, **1030** for converting the first stage beamforming output to digital representation. The digital conversion is received from the A/D convertors **1030**, **1028** by a customer ASIC such as a FPGA **1026** to complete the second stage beamforming. The FPGA Digital beamforming **1026** transmits information to the system controller **1024**. The system controller transmits information to a memory **1032** which may send a signal back to the FPGA Digital Beam forming **1026**. Alternatively, the system controller **1024** may transmit information to the custom USB3 Chipset **1022**. The USB3 Chipset **1022** may then transmit information to a DC-DC convertor **1034**. In turn, the DC-DC convertor **1034** may transmit power from the interface unit **1020** to the ultrasound probe **1040**. Within the ultrasound probe **1040** a power supply **1042** may receive the power signal and interface with the transmit driver 1 **1050** to provide the power to the front end integration probe. The power supply can include a battery to enable wireless operation of the transducer assembly. A wireless transceiver can be integrated into controller circuit or a separate communications circuit to enable wireless transfer of image data and control signals.

The host computer's **1082** custom or USB3 Chipset **1022** may be used to provide a communication link between the custom or USB3 Chipset **1012** to transmits a signal to the microprocessor **1014**. The microprocessor **1014** then may display information or send information to a device **1075**.

FIG. **11** is a detailed schematic block diagram of an exemplary embodiment of the ultrasound engine **108** (i.e., the front-end ultrasound specific circuitry) and an exemplary embodiment of the computer motherboard **106** (i.e., the host computer) of the ultrasound device illustrated in FIGS. **1** and **2**A. The components of the ultrasound engine **108** and/or the computer motherboard **106** may be implemented in application-specific integrated circuits (ASICs). Exemplary ASICs have a high channel count and can pack 32 or more channels per chip in some exemplary embodiments. One of ordinary skill in the art will recognize that the ultrasound engine **108** and the computer motherboard **106** may include more or fewer modules than those shown. For example, the ultrasound engine **108** and the computer motherboard **106** may include the modules shown in FIG. **17**.

A transducer array **152** is configured to transmit ultrasound waves to and receive reflected ultrasound waves from one or more image targets **1102**. The transducer array **152** is coupled to the ultrasound engine **108** using one or more cables **1104**.

The ultrasound engine **108** includes a high-voltage transmit/receive (TR) module **1106** for applying drive signals to the transducer array **152** and for receiving return echo signals from the transducer array **152**. The ultrasound engine **108** includes a pre-amp/time gain compensation (TGC) module **1108** for amplifying the return echo signals and applying suitable TGC functions to the signals. The ultrasound engine **108** includes a sampled-data beamformer **1110** that the delay coefficients used in each channel after the return echo signals have been amplified and processed by the pre-amp/TGC module **1108**.

In some exemplary embodiments, the high-voltage TR module **1106**, the pre-amp/TGC module **1108**, and the sample-interpolate receive beamformer **1110** may each be a silicon chip having 8 to 64 channels per chip, but exemplary embodiments are not limited to this range. In certain embodiments, the high-voltage TR module **1106**, the pre-amp/TGC module **1108**, and the sample-interpolate receive beamformer **1110** may each be a silicon chip having 8, 16, 32, 64 channels, and the like. As illustrated in FIG. **11**, an exemplary TR module **1106**, an exemplary pre-amp/TGC module **1108** and an exemplary beamformer **1110** may each take the form of a silicon chip including 32 channels.

The ultrasound engine **108** includes a first-in first-out (FIFO) buffer module **1112** which is used for buffering the processed data output by the beamformer **1110**. The ultrasound engine **108** also includes a memory **1114** for storing program instructions and data, and a system controller **1116** for controlling the operations of the ultrasound engine modules.

The ultrasound engine **108** interfaces with the computer motherboard **106** over a communications link **112** which can follow a standard high-speed communications protocol, such as the Fire Wire (IEEE 1394 Standards Serial Interface) or fast (e.g., 200-400 Mbits/second or faster) Universal Serial Bus (USB 2.0 USB 3.0), protocol. The standard communication link to the computer motherboard operates at least at 400 Mbits/second or higher, preferably at 800 Mbits/second or higher. Alternatively, the link **112** can be a wireless connection such as an infrared (IR) link. The ultrasound engine **108** includes a communications chipset **1118** (e.g., a Fire Wire chipset) to establish and maintain the communications link **112**.

Similarly, the computer motherboard **106** also includes a communications chipset **1120** (e.g., a Fire Wire chipset) to establish and maintain the communications link **112**. The computer motherboard **106** includes a core computer-readable memory **1122** for storing data and/or computer-executable instructions for performing ultrasound imaging operations. The memory **1122** forms the main memory for the computer and, in an exemplary embodiment, may store about 4 GB of DDR3 memory. The computer motherboard **106** also includes a microprocessor **1124** for executing computer-executable instructions stored on the core computer-readable memory **1122** for performing ultrasound imaging processing operations. An exemplary microprocessor **1124** may be an off-the-shelf commercial computer processor, such as an Intel Core-i5 processor. Another exemplary microprocessor **1124** may be a digital signal processor (DSP) based processor, such as one or more DaVinci™ processors from Texas Instruments. The computer motherboard **106** also includes a display controller **1126** for controlling a display device that may be used to display ultrasound data, scans and maps.

Exemplary operations performed by the microprocessor **1124** include, but are not limited to, down conversion (for generating I, Q samples from received ultrasound data), scan conversion (for converting ultrasound data into a display format of a display device), Doppler processing (for determining and/or imaging movement and/or flow information from the ultrasound data), Color Flow processing (for generating, using autocorrelation in one embodiment, a color-coded map of Doppler shifts superimposed on a B-mode ultrasound image), Power Doppler processing (for determining power Doppler data and/or generating a power Doppler map), Spectral Doppler processing (for determining spectral Doppler data and/or generating a spectral Doppler map), and post signal processing. These operations are described in further detail in WO 03/079038 A2, filed Mar. 11, 2003, titled "Ultrasound Probe with Integrated Electronics," the entire contents of which are expressly incorporated herein by reference.

To achieve a smaller and lighter portable ultrasound devices, the ultrasound engine **108** includes reduction in overall packaging size and footprint of a circuit board providing the ultrasound engine **108**. To this end, exemplary embodiments provide a small and light portable ultrasound device that minimizes overall packaging size and footprint while providing a high channel count. In some embodiments, a high channel count circuit board of an exemplary ultrasound engine may include one or more multi-chip modules in which each chip provides multiple channels, for example, 32 channels. The term "multi-chip module," as used herein, refers to an electronic package in which multiple integrated circuits (IC) are packaged into a unifying substrate, facilitating their use as a single component, i.e., as a larger IC. A multi-chip module may be used in an exemplary circuit board to enable two or more active IC components integrated on a High Density Interconnection (HDI) substrate to reduce the overall packaging size. In an exemplary embodiment, a multi-chip module may be assembled by vertically stacking a transmit/receive (TR) silicon chip, an amplifier silicon chip and a beamformer silicon chip of an ultrasound engine. A single circuit board of the ultrasound engine may include one or more of these multi-chip modules to provide a high channel count, while minimizing the overall packaging size and footprint of the circuit board.

FIG. **12** depicts a schematic side view of a portion of a circuit board **1200** including a multi-chip module assembled in a vertically stacked configuration. Two or more layers of active electronic integrated circuit components are integrated vertically into a single circuit. The IC layers are oriented in spaced planes that extend substantially parallel to one another in a vertically stacked configuration. In FIG. **12**, the circuit board includes an HDI substrate **1202** for supporting the multi-chip module. A first integrated circuit chip **1204** including, for example, a first beamformer device is coupled to the substrate **1202** using any suitable coupling mechanism, for example, epoxy application and curing. A first spacer layer **1206** is coupled to the surface of the first integrated circuit chip **1204** opposite to the substrate **1202** using, for example, epoxy application and curing. A second integrated circuit chip **1208** having, for example, a second beamforer device is coupled to the surface of the first spacer layer **1206** opposite to the first integrated circuit chip **1204** using, for example, epoxy application and curing. A metal frame **1210** is provided for mechanical and/or electrical connection among the integrated circuit chips. An exemplary metal frame **1210** may take the form of a leadframe. The first integrated circuit chip **1204** may be coupled to the metal frame **1210** using wiring **1212**. The second integrated circuit chip **1208** may be coupled to the same metal frame **1210** using wiring **1214**. A packaging **1216** is provided to encapsulate the multi-chip module assembly and to maintain the multiple integrated circuit chips in substantially parallel arrangement with respect to one another.

As illustrated in FIG. **12**, the vertical three-dimensional stacking of the first integrated circuit chip **1204**, the first spacer layer **1206** and the second integrated circuit chip **1208** provides high-density functionality on the circuit board while minimizing overall packaging size and footprint (as compared to an ultrasound engine circuit board that does not employ a vertically stacked multi-chip module). One of ordinary skill in the art will recognize that an exemplary multi-chip module is not limited to two stacked integrated circuit chips. Exemplary numbers of chips vertically integrated in a multi-chip module may include, but are not limited to, two, three, four, five, six, seven, eight, and the like.

In one embodiment of an ultrasound engine circuit board, a single multi-chip module as illustrated in FIG. **12** is provided. In other embodiments, a plurality of multi-chip modules also illustrated in FIG. **12**. In an exemplary embodiment, a plurality of multi-chip modules (for example, two multi-chip modules) may be stacked vertically on top of one another on a circuit board of an ultrasound engine to further minimize the packaging size and footprint of the circuit board.

In addition to the need for reducing the footprint, there is also a need for decreasing the overall package height in multi-chip modules. Exemplary embodiments may employ wafer thinning to sub-hundreds micron to reduce the package height in multi-chip modules.

Any suitable technique can be used to assemble a multi-chip module on a substrate. Exemplary assembly techniques include, but are not limited to, laminated MCM (MCM-L) in which the substrate is a multi-layer laminated printed circuit board, deposited MCM (MCM-D) in which the multi-chip modules are deposited on the base substrate using thin film technology, and ceramic substrate MCM (MCM-C) in which several conductive layers are deposited on a ceramic substrate and embedded in glass layers that layers are co-fired at high temperatures (HTCC) or low temperatures (LTCC).

FIG. **13** is a flowchart of an exemplary method for fabricating a circuit board including a multi-chip module assembled in a vertically stacked configuration. In step **1302**, a HDI substrate is fabricated or provided. In step **1304**, a metal frame (e.g., leadframe) is provided. In step **1306**, a first IC layer is coupled or bonded to the substrate using, for example, epoxy application and curing. The first IC layer is wire bonded to the metal frame. In step **1308**, a spacer layer is coupled to the first IC layer using, for example, epoxy application and curing, so that the layers are stacked vertically and extend substantially parallel to each other. In step **1310**, a second IC layer is coupled to the spacer layer using, for example, epoxy application and curing, so that all of the layers are stacked vertically and extend substantially parallel to one another. The second IC layer is wire bonded to the metal frame. In step **1312**, a packaging is used to encapsulate the multi-chip module assembly.

Exemplary chip layers in a multi-chip module may be coupled to each other using any suitable technique. For example, in the embodiment illustrated in FIG. **12**, spacer layers may be provided between chip layers to spacedly separate the chip layers. Passive silicon layers, die attach paste layers and/or die attach film layers may be used as the spacer layers. Exemplary spacer techniques that may be used in fabricating a multi-chip module is further described in Toh C H et al., "Die Attach Adhesives for 3D Same-Sized Dies Stacked Packages," the 58th Electronic Components and Technology Conference (ECTC2008), pp. 1538-43, Florida, US (27-30 May 2008), the entire contents of which are expressly incorporated herein by reference.

Important requirements for the die attach (DA) paste or film is excellent adhesion to the passivation materials of adjacent dies. Also, a uniform bond-link thickness (BLT) is required for a large die application. In addition, high cohesive strength at high temperatures and low moisture absorption are preferred for reliability.

FIGS. **14**A-**14**C are schematic side views of exemplary multi-chip modules, including vertically stacked dies, that may be used in accordance with exemplary embodiments. Both peripheral and center pads wire bond (WB) packages are illustrated and may be used in wire bonding exemplary chip layers in a multi-chip module. FIG. **14**A is a schematic side view of a multi-chip module including four vertically stacked dies in which the dies are spacedly separated from one another by passive silicon layers with a 2-in-1 dicing die attach film (D-DAF). FIG. **14**B is a schematic side view of a multi-chip module including four vertically stacked dies in which the dies are spacedly separated from one another by DA film-based adhesives acting as die-to-die spacers. FIG. **14**C is a schematic side view of a multi-chip module including four vertically stacked dies in which the dies are spacedly separated from one another by DA paste or film-based adhesives acting as die-to-die spacers. The DA paste or film-based adhesives may have wire penetrating capability in some exemplary embodiments. In the exemplary multi-chip module of FIG. **14**C, film-over wire (FOW) is used to allow long wire bonding and center bond pads stacked die packages. FOW employs a die-attach film with wire penetrating capability that allows the same or similar-sized wire-bonded dies to be stacked directly on top of one another without passive silicon spacers. This solves the problem of stacking same or similar-sized dies directly on top of each other, which otherwise poses a challenge as there is no or insufficient clearance for the bond wires of the lower dies.

The DA material illustrated in FIGS. **14**B and **14**C preferably maintain a bond-line thickness (BLT) with little to no voiding and bleed out through the assembly process. Upon assembly, the DA materials sandwiched between the dies maintain an excellent adhesion to the dies. The material properties of the DA materials are tailored to maintain high cohesive strength for high temperature reliability stressing without bulk fracture. The material properties of the DA materials are tailored to also minimize or preferably eliminate moisture accumulation that may cause package reliability failures (e.g., popcorning whereby interfacial or bulk fractures occur as a result of pressure build-up from moisture in the package).

FIG. **15** is a flowchart of certain exemplary methods of die-to-die stacking using (a) passive silicon layers with a 2-in-1 dicing die attach film (D-DAF), (b) DA paste, (c) thick DA-film, and (d) film-over wire (FOW) that employs a die-attach film with wire penetrating capability that allows the same or similar-sized wire-bonded dies to be stacked directly on top of one another without passive silicon spacers. Each method performs backgrinding of wafers to reduce the wafer thickness to enable stacking and high density packaging of integrated circuits. The wafers are sawed to separate the individual dies. A first die is bonded to a substrate of a multi-chip module using, for example, epoxy application and curing in an oven. Wire bonding is used to couple the first die to a metal frame.

In method (A), a first passive silicon layer is bonded to the first die in a stacked manner using a dicing die-attach film (D-DAF). A second die is bonded to the first passive layer in a stacked manner using D-DAF. Wire bonding is used to couple the second die to the metal frame. A second passive silicon layer is bonded to the second die in a stacked manner using D-DAF. A third die is bonded to the second passive layer in a stacked manner using D-DAF. Wire bonding is used to couple the third die to the metal frame. A third passive silicon layer is bonded to the third die in a stacked manner using D-DAF. A fourth die is bonded to the third passive layer in a stacked manner using D-DAF. Wire bonding is used to couple the fourth die to the metal frame.

In method (B), die attach (DA) paste dispensing and curing is repeated for multi-thin die stack application. DA paste is dispensed onto a first die, and a second die is provided on the DA paste and cured to the first die. Wire bonding is used to couple the second die to the metal frame. DA paste is dispensed onto the second die, and a third die is provided on the DA paste and cured to the second die. Wire bonding is used to couple the third die to the metal frame. DA paste is dispensed onto the third die, and a fourth die is provided on the DA paste and cured to the third die. Wire bonding is used to couple the fourth die to the metal frame.

In method (C), die attach films (DAF) are cut and pressed to a bottom die and a top die is then placed and thermal compressed onto the DAF. For example, a DAF is pressed to the first die and a second die is thermal compressed onto the DAF. Wire bonding is used to couple the second die to the metal frame. Similarly, a DAF is pressed to the second die and a third die is thermal compressed onto the DAF. Wire bonding is used to couple the third die to the metal frame. A DAF is pressed to the third die and a fourth die is thermal compressed onto the DAF. Wire bonding is used to couple the fourth die to the metal frame.

In method (D), film-over wire (FOW) employs a die-attach film with wire penetrating capability that allows the same or similar-sized wire-bonded dies to be stacked directly on top of one another without passive silicon spacers. A second die is bonded and cured to the first die in a stacked manner. Film-over wire bonding is used to couple the second die to the metal frame. A third die is bonded and cured to the first die in a stacked manner. Film-over wire bonding is used to couple the third die to the metal frame. A fourth die is bonded and cured to the first die in a stacked manner. Film-over wire bonding is used to couple the fourth die to the metal frame.

After the above-described steps are completed, in each method (a)-(d), wafer molding and post-mold curing (PMC) are performed. Subsequently, ball mount and singulation are performed.

Further details on the above-described die attachment techniques are provided in TOH C H et al., "Die Attach Adhesives for 3D Same-Sized Dies Stacked Packages," the 58th Electronic Components and Technology Conference (ECTC2008), pp. 1538-43, Florida, US (27-30 May 2008), the entire contents of which are expressly incorporated herein by reference.

FIG. **16** is a schematic side view of a multi-chip module **1600** including a TR chip **1602**, an amplifier chip **1604** and a beamformer chip **1606** vertically integrated in a vertically stacked configuration on a substrate **1614**. Any suitable technique illustrated in FIGS. **12-15** may be used to fabricate the multi-chip module. One of ordinary skill in the art will recognize that the particular order in which the chips are stacked may be different in other embodiments. First and second spacer layers **1608**, **1610** are provided to spacedly separate the chips **1602**, **1604**, **1606**. Each chip is coupled to a metal frame (e.g., a leadframe) **1612**. In certain exemplary embodiments, heat transfer and heat sink mechanisms may be provided in the multi-chip module to sustain high temperature reliability stressing without bulk failure. Other components of FIG. **16** are described with reference to FIGS. **12** and **14**.

In this exemplary embodiment, each multi-chip module may handle the complete transmit, receive, TGC amplification and beam forming operations for a large number of channels, for example, 32 channels. By vertically integrating the three silicon chips into a single multi-chip module, the space and footprint required for the printed circuit board is further reduced. A plurality of multi-chip modules may be provided on a single ultrasound engine circuit board to further increase the number of channels while minimizing the packaging size and footprint. For example, a 128 channel ultrasound engine circuit board **108** can be fabricated within exemplary planar dimensions of about 10 cm× about 10 cm, which is a significant improvement of the space requirements of conventional ultrasound circuits. A single circuit board of an ultrasound engine including one or more multi-chip modules may have 16 to 128 channels in preferred embodiments. In certain embodiments, a single circuit board of an ultrasound engine including one or more multi-chip modules may have 16, 32, 64, 128 channels, and the like.

FIG. **17** is a detailed schematic block diagram of an exemplary embodiment of the ultrasound engine **108** (i.e., the front-end ultrasound specific circuitry) and an exemplary embodiment of the computer motherboard **106** (i.e., the host computer) provided as a single board complete ultrasound system. An exemplary single board ultrasound system as illustrated in FIG. **17** may have exemplary planar dimensions of about 25 cm× about 18 cm, although other dimensions are possible. The single board complete ultrasound system of FIG. **17** may be implemented in the ultrasound device illustrated in FIGS. **1**, **2**A, **2**B, and **9**A, and may be used to perform the operations depicted in FIGS. **3-8**, **9**B, and 10.

The ultrasound engine **108** includes a probe connector **114** to facilitate the connection of at least one ultrasound probe/transducer. In the ultrasound engine **108**, a TR module, an amplifier module and a beamformer module may be vertically stacked to form a multi-chip module as shown in FIG. **16**, thereby minimizing the overall packaging size and footprint of the ultrasound engine **108**. The ultrasound engine **108** may include a first multi-chip module **1710** and a second multi-chip module **1712**, each including a TR chip, an ultrasound pulser and receiver, an amplifier chip including a time-gain control amplifier, and a sample-data beamformer chip vertically integrated in a stacked configuration as shown in FIG. **16**. The first and second multi-chip modules **1710**, **1712** may be stacked vertically on top of each other to further minimize the area required on the circuit board. Alternatively, the first and second multi-chip modules **1710**, **1712** may be disposed horizontally on the circuit board. In an exemplary embodiment, the TR chip, the amplifier chip and the beamformer chip is each a 32-channel chip, and each multi-chip module **1710**, **1712** has 32 channels. One of ordinary skill in the art will recognize that exemplary ultrasound engines **108** may include, but are not limited to, one, two, three, four, five, six, seven, eight multi-chip modules. Note that in a preferred embodiment the system can be configured with a first beamformer in the transducer housing and a second beamformer in the tablet housing.

The ASICs and the multi-chip module configuration enable a 128-channel complete ultrasound system to be implemented on a small single board in a size of a tablet computer format. An exemplary 128-channel ultrasound engine **108**, for example, can be accommodated within exemplary planar dimensions of about 10 cm× about 10 cm, which is a significant improvement of the space requirements of conventional ultrasound circuits. An exemplary 128-channel ultrasound engine **108** can also be accommodated within an exemplary area of about 100 cm^2.

The ultrasound engine **108** also includes a clock generation complex programmable logic device (CPLD) **1714** for generating timing clocks for performing an ultrasound scan using the transducer array. The ultrasound engine **108** includes an analog-to-digital converter (ADC) **1716** for converting analog ultrasound signals received from the transducer array to digital RF formed beams. The ultrasound engine **108** also includes one or more delay profile and waveform generator field programmable gate arrays (FPGA) **1718** for managing the receive delay profiles and generating the transmit waveforms. The ultrasound engine **108** includes a memory **1720** for storing the delay profiles for ultrasound scanning. An exemplary memory **1720** may be a single DDR3 memory chip. The ultrasound engine **108** includes a scan sequence control field programmable gate array (FPGA) **1722** configured to manage the ultrasound scan sequence, transmit/receiving timing, storing and fetching of profiles to/from the memory **1720**, and buffering and moving of digital RF data streams to the computer motherboard **106** via a high-speed serial interface **112**. The high-speed serial interface **112** may include Fire Wire or other serial or parallel bus interface between the computer motherboard **106** and the ultrasound engine **108**. The ultrasound engine **108** includes a communications chipset **1118** (e.g., a Fire Wire chipset) to establish and maintain the communications link **112**.

A power module **1724** is provided to supply power to the ultrasound engine **108**, manage a battery charging environment and perform power management operations. The power module **1724** may generate regulated, low noise power for the ultrasound circuitry and may generate high voltages for the ultrasound transmit pulser in the TR module.

The computer motherboard **106** includes a core computer-readable memory **1122** for storing data and/or computer-executable instructions for performing ultrasound imaging operations. The memory **1122** forms the main memory for the computer and, in an exemplary embodiment, may store about 4 Gb of DDR3 memory. The memory **1122** may include a solid state hard drive (SSD) for storing an operating system, computer-executable instructions, programs and image data. An exemplary SSD may have a capacity of about 128 GB.

The computer motherboard **106** also includes a microprocessor **1124** for executing computer-executable instructions stored on the core computer-readable memory **1122** for performing ultrasound imaging processing operations. Exemplary operations include, but are not limited to, down conversion, scan conversion, Doppler processing, Color Flow processing, Power Doppler processing, Spectral Doppler processing, and post signal processing. An exemplary microprocessor **1124** may be an off-the-shelf commercial computer processor, such as an Intel Core-i5 processor. Another exemplary microprocessor **1124** may be a digital signal processor (DSP) based processor, such as DaVinci™ processors from Texas Instruments.

The computer motherboard **106** includes an input/output (I/O) and graphics chipset **1704** which includes a co-processor configured to control I/O and graphic peripherals such as USB ports, video display ports and the like. The computer motherboard **106** includes a wireless network adapter **1702** configured to provide a wireless network connection. An exemplary adapter **1702** supports 802.11g and 802.11n standards. The computer motherboard **106** includes a display controller **1126** configured to interface the computer motherboard **106** to the display **104**. The computer motherboard **106** includes a communications chipset **1120** (e.g., a Fire Wire chipset or interface) configured to provide a fast data communication between the computer motherboard **106** and the ultrasound engine **108**. An exemplary communications chipset **1120** may be an IEEE 1394b 800 Mbit/sec interface. Other serial or parallel interfaces **1706** may alternatively be provided, such as USB3, Thunder-Bolt, PCIe, and the like. A power module **1708** is provided to supply power to the computer motherboard **106**, manage a battery charging environment and perform power management operations.

An exemplary computer motherboard **106** may be accommodated within exemplary planar dimensions of about 12 cm× about 10 cm. An exemplary computer motherboard **106** can be accommodated within an exemplary area of about 120 cm^2.

FIG. **18** is a perspective view of an exemplary portable ultrasound system **100** provided in accordance with exemplary embodiments. The system **100** includes a housing **102** that is in a tablet form factor as illustrated in FIG. **18**, but that may be in any other suitable form factor. An exemplary housing **102** may have a thickness below 2 cm and preferably between 0.5 and 1.5 cm. A front panel of the housing **102** includes a multi-touch LCD touch screen display **104** that is configured to recognize and distinguish one or more multiple and/or simultaneous touches on a surface of the touch screen display **104**. The surface of the display **104** may be touched using one or more of a user's fingers, a user's hand or an optional stylus 1802. The housing **102** includes one or more I/O port connectors **116** which may include, but are not limited to, one or more USB connectors, one or more SD cards, one or more network mini display ports, and a DC power input. The embodiment of housing **102** in FIG. **18** can also be configured within a palm-carried form factor having dimensions of 150 mm×100 mm×15 mm (a volume of 225000 mm^3) or less. The housing **102** can have a weight of less than 200 g. Optionally, cabling between the transducer array and the display housing can include interface circuitry **1020** as described herein. The interface circuitry **1020** can include, for example, beamforming circuitry and/or A/D circuitry in a pod that dangles from the tablet. Separate connectors **1025**, **1027** can be used to connect the dangling pod to the transducer probe cable. The connector **1027** can include probe identification circuitry as described herein. The unit **102** can include a camera, a microphone and a speaker as well as wireless telephone circuitry for voice and data communications as well as voice activated software that can be used to control the ultrasound imaging operations described herein.

The housing **102** includes or is coupled to a probe connector **114** to facilitate connection of at least one ultrasound probe/transducer **150**. The ultrasound probe **150** includes a transducer housing including one or more transducer arrays **152**. The ultrasound probe **150** is couplable to the probe connector **114** using a housing connector **1804** provided along a flexible cable **1806**. One of ordinary skill in the art will recognize that the ultrasound probe **150** may be coupled to the housing **102** using any other suitable mechanism, for example, an interface housing that includes circuitry for performing ultrasound-specific operations like beamforming. Other exemplary embodiments of ultrasound systems are described in further detail in WO 03/079038 A2, filed Mar. 11, 2003, titled "Ultrasound Probe with Integrated Electronics," the entire contents of which is expressly incorporated herein by reference. Preferred embodiments can employ a wireless connection between the hand-held transducer probe **150** and the display housing. Beamformer electronics can be incorporated into probe housing **150** to provide beamforming of subarrays in a 1D or 2D transducer array as described herein. The display housing can be sized to be held in the palm of the user's hand and can include wireless network connectivity to public access networks such as the internet.

FIG. **19** illustrates an exemplary view of a main graphical user interface (GUI) **1900** rendered on the touch screen display **104** of the portable ultrasound system **100** of FIG. **18**. The main GUI **1900** may be displayed when the ultrasound system **100** is started. To assist a user in navigating the main GUI **1900**, the GUI may be considered as including four exemplary work areas: a menu bar **1902**, an image display window **1904**, an image control bar **1906**, and a tool bar **1908**. Additional GUI components may be provided on the main GUI **1900** to, for example, enable a user to close, resize and exit the GUI and/or windows in the GUI.

The menu bar **1902** enables a user to select ultrasound data, images and/or videos for display in the image display window **1904**. The menu bar **1902** may include, for example, GUI components for selecting one or more files in a patient folder directory and an image folder directory. The image display window **1904** displays ultrasound data, images and/or videos and may, optionally, provide patient information. The tool bar **1908** provides functionalities associated with an image or video display including, but not limited to, a save button for saving the current image and/or video to a file, a save Loop button that saves a maximum allowed number of previous frames as a Cine loop, a print button for printing the current image, a freeze image button for freezing an image, a playback toolbar for controlling aspects of playback of a Cine loop, and the like. Exemplary GUI functionalities that may be provided in the main GUI **1900** are described in further detail in WO 03/079038 A2, filed Mar. 11, 2003, titled "Ultrasound Probe with Integrated Electronics," the entire contents of which are expressly incorporated herein by reference.

The image control bar **1906** includes touch controls that may be operated by touch and touch gestures applied by a user directly to the surface of the display **104**. Exemplary touch controls may include, but are not limited to, a 2D touch control **408**, a gain touch control **410**, a color touch control **412**, a storage touch control **414**, a split touch control **416**, a PW imaging touch control **418**, a beamsteering touch control **20**, an annotation touch control **422**, a dynamic range operations touch control **424**, a Teravision™ touch control **426**, a map operations touch control **428**, and a needle guide touch control **428**. These exemplary touch controls are described in further detail in connection with FIGS. **4***a*-**4***c*.

FIG. **20** depicts an illustrative embodiment of exemplary medical ultrasound imaging equipment **2000**, implemented in the form factor of a tablet in accordance with the invention. The table may have the dimensions of 12.5"×1.25"×8.75" or 31.7 cm×3.175 cm×22.22 cm but it may also be in any other suitable form factor having a volume of less than 2500 cm^3 and a weight of less than 8 lbs. As shown in FIG. **20**, the medical ultrasound imaging equipment **2000**, includes a housing **2030**, a touch screen display **2010**, wherein ultrasound images **2010**, and ultra sound data **2040**, can be displayed and ultrasound controls **2020**, are configured to be controlled by a touchscreen display **2010**. The housing **2030**, may have a front panel **2060** and a rear panel **2070**. The touchscreen display **2010**, forms the front panel **2060**, and includes a multi-touch LCD touch screen that can recognize and distinguish one or more multiple and or simultaneous touches of the user on the touchscreen display **2010**. The touchscreen display **2010** may have a capacitive multi-touch and AVAH LCD screen. For example, the capacitive multi-touch and AVAH LCD screen may enable a user to view the image from multi angles without losing resolution. In another embodiment, the user may utilize a stylus for data input on the touch screen. The tablet can include an integrated foldable stand that permits a user to swivel the stand from a storage position that conforms to the tablet form factor so that the device can lay flat on the rear panel, or alternatively, the user can swivel the stand to enable the tablet to stand at an upright position at one of a plurality of oblique angles relative to a support surface.

Capacitive touchscreen module comprises an insulator for example glass, coated with a transparent conductor, such as indium tin oxide. The manufacturing process may include a bonding process among glass, x-sensor film, y-sensor film and a liquid crystal material. The tablet is configured to allow a user to perform multi-touch gestures such as pinching and stretching while wearing a dry or a wet glove. The surface of the screen registers the electrical conductor making contact with the screen. The contact distorts the screens electrostatic field resulting in measurable changes in capacitance. A processor then interprets the change in the electrostatic field. Increasing levels of responsiveness are enabled by reducing the layers and by producing touch screens with "in-cell" technology. "In-cell" technology eliminates layers by placing the capacitors inside the display. Applying "in-cell" technology reduces the visible distance between the user's finger and the touchscreen target, thereby creating a more directive contact with the content displayed and enabling taps and gestures to have an increase in responsiveness.

FIG. **21** illustrates a preferred cart system for a modular ultrasound imaging system in accordance with the invention. The cart system **2100** uses a base assembly **2122** including a docking bay that receives the tablet. The cart configuration **2100** is configured to dock tablet **2104**, including a touch screen display **2102**, to a cart **2108**, which can include a full operator console **2124**. After the tablet **2104**, is docked to the cart stand **2108**, the system forms a full feature roll about system. The full feature roll about system may include, an adjustable height device **2106**, a gel holder **2110**, and a storage bin **2114**, a plurality of wheels **2116**, a hot probe holder **2120**, and the operator console **2124**. The control devices may include a keyboard **2112** on the operator console **2124** that may also have other peripherals added such as a printer or a video interface or other control devices.

FIG. **22** illustrate a preferred cart system, for use in embodiments with a modular ultrasound imaging system in accordance with the invention. The cart system **2200** may be configured with a vertical support member **2212**, coupled to a horizontal support member **2028**. An auxiliary device connector **2018**, having a position for auxiliary device attachment **2014**, may be configured to connect to the vertical support member **2212**. A 3 port Probe MUX connection device **2016** may also be configured to connect to the tablet. A storage bin **2224** can be configured to attach by a storage bin attachment mechanism **2222**, to vertical support member **2212**. The cart system may also include a cord management system **2226**, configured to attach to the vertical support member. The cart assembly **2200** includes the support beam **2212** mounted on a base **2228** having wheels **2232** and a battery **2230** that provides power for extended operation of the tablet. The assembly can also include an accessory holder **2224** mounted with height adjustment device **2226**. Holders **2210**, **2218** can be mounted on beam **2212** or on console panel **2214**. The multiport probe multiplex device **2216** connects to the tablet to provide simultaneous connection of several transducer probes which the user can select in sequence with the displayed virtual switch. A moving touch gesture, such as a three finger flick on the displayed image or touching of a displayed virtual button or icon can switch between connected probes.

FIG. **23** illustrates preferred cart mount system for a modular ultrasound imaging system in accordance with the invention. Arrangement **2300** depicts the tablet **2302**, coupled to the docking station **2304**. The docking station **2304** is affixed to the attachment mechanism **2306**. The attachment mechanism **2306** may include a hinged member **2308**, allowing for the user display to tilted into a user desired position. The attachment mechanism **2306** is attached to the vertical member **2312**. A tablet **2302** as described herein can be mounted on the base docking unit **2304** which is mounted to a mount assembly **2306** on top of beam **2212**. The base unit **2304** includes cradle **2310**, electrical connectors **2305** and a port **2307** to connect to the system **2302** to battery **2230** and multiplexor device **2216**.

FIG. **24** illustrates preferred cart system **2400** modular ultrasound imaging system in accordance with the invention in which tablet **2402** is connected on mounting assembly **2406** with connector **2404**. Arrangement **2400** depicts the tablet **2402**, coupled to the vertical support member **2408**, via attachment mechanism **2404** without the docking element **2304**. Attachment mechanism **2404** may include a hinged member **2406** for display adjustment.

FIGS. **25**A and **25**B illustrate a multi-function docking station. FIG. **25**A illustrates docking station **2502**, and tablet **2504**, having a base assembly **2506**, that mates to the docking station **2502**. The tablet **2504**, and the docking station **2502**, may be electrically connected. The tablet **2504** may be released from docking station **2502**, by engaging the release mechanism **2508**. The docking station **2502** may contain a transducer port **2512**, for connection of a transducer probe **2510**. The docking station **2502** can contain 3 USB 3.0 ports, a LAN port, a headphone jack and a power connector for charging. FIG. **25**B illustrates a side view of the tablet **2504**, and docking station **2502**, having a stand in accordance with the preferred embodiments of the present invention. The docking station may include an adjustable stand/handle **2526**. The adjustable stand/handle **2526** may be tilted for multiple viewing angles. The adjustable stand/handle **2526** may be flipped up for transport purposes. The side view also illustrates a transducer port **2512**, and a transducer probe connector **2510**.

FIG. **26** illustrates a 2D imaging mode of operation with a modular ultrasound imaging system in accordance with the invention. The touch screen of table **2504** may display images obtained by 2-dimensional transducer probe using a 256 digital beamformer channels. The 2-dimensional image window **2602** depicts a 2-dimensional image scan **2604**. The 2-dimensional image may be obtained using flexible frequency scans **2606**, wherein the control parameters are represented on the tablet.

FIG. **27** illustrates a motion mode of operation with a modular ultrasound imaging system in accordance with the invention. The touch screen display of tablet **2700**, may display images obtained by a motion mode of operation. The touch screen display of tablet **2700**, may simultaneously display 2-dimensional **2706**, and motion mode imaging **2708**. The touch screen display of tablet **2700**, may display a 2-dimensional image window **2704**, with a 2-dimensional image **2706**. Flexible frequency controls **2702** displayed with the graphical user interface can be used to adjust the frequency from 2 MHz to 12 MHz.

FIG. **28** illustrates a color Doppler mode of operation with a modular ultrasound imaging system in accordance with the invention. The touch screen display of tablet **2800** displays images obtained by color Doppler mode of operation. A 2-dimensional image window **2806** is used as the base display. The color coded information **2808**, is overlaid on the 2-dimensional image **2810**. Ultrasound-based imaging of red blood cells are derived from the received echo of the transmitted signal. The primary characteristics of the echo signal are the frequency and the amplitude. Amplitude depends on the amount of moving blood within the volume sampled by the ultrasound beam. A high frame rate or high resolution can be adjusted with the display to control the quality of the scan. Higher frequencies may be generated by rapid flow and can be displayed in lighter colors, while lower frequencies are displayed in darker colors. Flexible frequency controls **2804**, and color Doppler scan information **2802**, may be displayed on the tablet display **2800**.

FIG. **29** illustrates a Pulsed wave Doppler mode of operation with a modular ultrasound imaging system in accordance with the invention. The touch screen display of tablet **2900**, may display images obtained by pulsed wave Doppler mode of operation. Pulsed wave Doppler scans produce a series of pulses used to analyse the motion of blood flow in a small region along a desired ultrasound cursor called the sample volume or sample gate **2012**. The tablet display **2900** may depict a 2-dimensional image **2902**, wherein the sample volume/sample gate **2012** is overlaid. The tablet display **2900** may use a mixed mode of operation **2906**, to depict a 2-dimensional image **2902**, and a time/doppler frequency shift **2910**. The time/doppler frequency shift **2910** can be converted into velocity and flow if an appropriate angle between the beam and blood flow is known. Shades of gray **2908**, in the time/doppler frequency shift **2910**, may represent the strength of signal. The thickness of the spectral signal may be indicative of laminar or turbulent flow. The tablet display **2900** can depict adjustable frequency controls **2904**.

FIG. **30** illustrates a triplex scan mode of operation with a modular ultrasound imaging system in accordance with the invention. The tablet display **3000** may include a 2-dimensional window **3002**, capable of displaying 2-dimensional images alone or in combination with the color Doppler or directional Doppler features. The touch screen display of tablet **3000**, may display images obtained by color Doppler mode of operation. A 2-dimensional image window **3002** is used as the base display. The color coded information **3004**, is overlaid **3006**, on the 2-dimensional image **3016**. The pulsed wave Doppler feature may be used alone or in combination with 2-dimensional imaging or the color Doppler imaging. The tablet display **3000** may include a pulsed wave Doppler scan represented by a sample volume/sample gate **3008**, overlaid over 2 dimensional images **3016**, or the color code overlaid **3006**, either alone or in combination. The tablet display **3000** may depict a split screen representing the time/doppler frequency shift **3012**. The time/doppler frequency shift **3012** can be converted into velocity and flow if an appropriate angle between the insolating beam and blood flow is known. Shades of gray **3014**, in the time/doppler frequency shift **3012**, may represent the strength of signal. The thickness of the spectral signal may be indicative of laminar or turbulent flow. The tablet display **3000** also may depict flexible frequency controls **3010**.

FIG. **31** illustrates a GUI home screen interface **3100**, for a user mode of operation, with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3100** may be displayed when the ultrasound system is started. To assist a user in navigating the GUI home screen **3100**, the home screen may be considered as including three exemplary work areas: a menu bar **3104**, an image display window **3102**, and an image control bar **3106**. Additional GUI components may be provided on the main GUI home screen **3100**, to enable a user to close, resize and exit the GUI home screen and/or windows in the GUI home screen.

The menu bar **3104** enables users to select ultrasound data, images and/or video for display in the image display window **3102**. The menu bar may include components for selecting one or more files in a patient folder directly and an image folder directory.

The image control bar **3106** includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a depth control touch controls **3108**, a 2-dimensional gain touch control **3110**, a full screen touch control **3112**, a text touch control **3114**, a split screen touch control **3116**, a ENV touch control **3118**, a CD touch control **3120**, a PWD touch control **3122**, a freeze touch control **3124**, a store touch control **3126**, and a optimize touch control **3128**.

FIG. **32** illustrates a GUI menu screen interface **3200**, for a user mode of operation, with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3200** may be displayed when the menu selection mode is triggered from the menu bar **3204** thereby initiating operation of the ultrasound system. To assist a user in navigating the GUI home screen **3100**, the home screen may be considered as including three exemplary work areas: a menu bar **3204**, an image display window **3202**, and an image control bar **3220**. Additional GUI components may be provided on the main GUI menu screen **3200** to enable a user to close, resize and exit the GUI menu screen and/or windows in the GUI menu screen, for example.

The menu bar **3204** enables users to select ultra sound data, images and/or video for display in the image display window **3202**. The menu bar **3204** may include touch control components for selecting one or more files in a patient folder directory and an image folder directory. Depicted in an expanded format, the menu bar may include exemplary touch control such as, a patient touch control **3208**, a pre-sets touch control **3210**, a review touch control **3212**, a report touch control **3214**, and a setup touch control **3216**.

The image control bar **3220** includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to depth control touch controls **3222**, a 2-dimensional gain touch control **3224**, a full screen touch control **3226**, a text touch control **3228**, a split screen touch control **3230**, a needle visualization ENV touch control **3232**, a CD touch control **3234**, a PWD touch control **3236**, a freeze touch control **3238**, a store touch control **3240**, and a optimize touch control **3242**.

FIG. **33** illustrates a GUI patient data screen interface **3300**, for a user mode of operation, with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3300**, may be displayed when the patient selection mode is triggered from the menu bar **3302**, when the ultrasound system is started. To assist a user in navigating the GUI patient data screen **3300**, the patient data screen may be considered as including five exemplary work areas: a new patient touch screen control **3304**, a new study touch screen control **3306**, a study list touch screen control **3308**, a work list touch screen control **3310**, and an edit touch screen control **3312**. Within each touch screen control, further information entry fields are available **3314**, **3316**. For example, patient information section **3314**, and study information section **3316**, may be used to record data.

Within the patient data screen **3300**, the image control bar **3318**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to accept study touch control **3320**, close study touch control **3322**, print touch control **3324**, print preview touch control **3326**, cancel touch control **3328**, a 2-dimensional touch control **3330**, freeze touch control **3332**, and a store touch control **3334**.

FIG. **34** illustrates a GUI patient data screen interface **3400**, for a user mode of operation with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3400**, may be displayed when the pre-sets selection mode **3404**, is triggered from the menu bar **3402**, when the ultrasound system is started.

Within the pre-sets screen **3400**, the image control bar **3408**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a save settings touch control **3410**, a delete touch control **3412**, CD touch control **3414**, PWD touch control **3416**, a freeze touch control **3418**, a store touch control **3420**, and a optimize touch control **3422**.

FIG. **35** illustrates a GUI review screen interface **3500**, for a user mode of operation, with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3500**, may be displayed when the pre-sets expanded review **3504**, selection mode **3404**, is triggered from the menu bar **3502**, when the ultrasound system is started.

Within the review screen **3500**, the image control bar **3516**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a thumbnail settings touch control **3518**, sync touch control **3520**, selection touch control **3522**, a previous image touch control **3524**, a next image touch control **3526**, a 2-dimensional image touch control **3528**, a pause image touch control **3530**, and a store image touch control **3532**.

A image display window **3506**, may allow the user to review images in a plurality of formats. Image display window **3506**, may allow a user to view images **3508**, **3510**, **3512**, **3514**, in combination or subset or allow any image **3508**, **3510**, **3512**, **3514**, to be viewed individually. The image display window **3506**, may be configured to display up to four images **3508**, **3510**, **3512**, **3514**, to be viewed simultaneously.

FIG. **36** illustrates a GUI Report Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3600**, may be displayed when the report expanded review **3604**, is triggered from the menu bar **3602**, when the ultrasound system is started. The display screen **3606**, contains the ultrasound report information **3626**. The user may use the worksheet section within the ultrasound report **3626**, to enter in comments, patient information and study information.

Within the report screen **3600**, the image control bar **3608**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a save touch control **3610**, a save as touch control **3612**, a print touch control **3614**, a print preview touch control **3616**, a close study touch control **3618**, a 2-dimensional image touch control **3620**, a freeze image touch control **3622**, and a store image touch control **3624**.

FIG. **37** illustrates a GUI Setup Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3700**, may be displayed when the report expanded review **3704**, is triggered from the menu bar **3702**, when the ultrasound system is started.

Within the setup expanded screen **3704**, the setup control bar **3744**, includes touch controls that may be operated by touch and touch gestures, applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a general touch control **3706**, a display touch control **3708**, a measurements touch control **3710**, annotation touch control **3712**, a print touch control **3714**, a store/acquire touch control **3716**, a DICOM touch control **3718**, an export touch control **3720**, and a study information image touch control **3722**. The touch controls may contain a display screen that allow the user to enter configuration information. For example, the general touch control **3706**, contains a configuration screen **3724**, wherein the user may enter configuration information. Additionally, the general touch control **3706**, contains a section allowing user configuration of the soft key docking position **3726**. FIG. **37**B depicts the soft key controls **3752**, with a right side alignment. FIG. **37**B further illustrates that activation of the soft key control arrow **3750**, will change the key alignment to the opposite side, in this case, left side alignment. FIG. **37**C depicts left side alignment of the soft key controls **3762**, the user may activate an orientation change by using the soft key control arrow **3760**, to change the position to right side alignment.

Within the review screen **3700**, the image control bar **3728**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include but are not limited to, a thumbnail settings touch control **3730**, sync touch control **3732**, selection touch control **3734**, a previous image touch control **3736**, a next image touch control **3738**, a 2-dimensional image touch control **3740**, and a pause image touch control **3742**.

FIG. **38** illustrates a GUI Setup Screen Interface for a user mode of operation with a modular ultrasound imaging system in accordance with the invention. The screen interface for a user mode of operation **3800**, may be displayed when the report expanded review **3804**, is triggered from the menu bar **3802**, when the ultrasound system is started.

Within the setup expanded screen **3804**, the setup control bar **3844**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a plurality of icons such as a general touch control **3806**, a display touch control **3808**, a measurements touch control **3810**, annotation touch control **3812**, a print touch control **3814**, a store/acquire touch control **3816**, a DICOM touch control **3818**, an export touch control **3820**, and a study information image touch control **3822**. The touch controls can contain a display screen that allow the user to enter store/acquire information. For example, the store/acquire touch control **3816**, contains a configuration screen **3802**, wherein the user may enter configuration information. The user can actuate a virtual keyboard allowing the user to enter alphanumeric characters in different touch activated fields. Additionally, the store/acquire touch control **3802**, contains a section allowing user enablement of retrospective acquisition **3804**. When the user enables the store function, the system is defaulted to store prospective cine loops. If the user enables the enable retrospective capture, the store function may collect the cine loop retrospectively.

Within the setup screen **3800**, the image control bar **3828**, includes touch controls that may be operated by touch and touch gestures applied by the user directly to the surface of the display. Exemplary touch controls may include, but are not limited to a thumbnail settings touch control **3830**, synchronize touch control **3832**, selection touch control **3834**, a previous image touch control **3836**, a next image touch control **3838**, a 2-dimensional image touch control **3840**, and a pause image touch control **3842**.

FIGS. **39**A and **39**B illustrate an XY bi-plane probe consisting of two one dimensional, multi-element arrays. The arrays may be constructed where one array is on top of the other with a polarization axis of each array being aligned in the same direction. The elevation axis of the two arrays can be at a right angle or orthogonal to one another. Exemplary embodiments can employ transducer assemblies such as those described in U.S. Pat. No. 7,066,887, the entire contents of which is incorporated herein by reference, or transducers sold by Vernon of Tours Cedex, France, for example. Illustrated by FIG. **39**A, the array orientation is represented by arrangement **3900**. The polarization axis **3908**, of both arrays are pointed in the z-axis **3906**. The elevation axis of the bottom array, is pointed in y-direction **3902**, and the elevation axis of the top array, is in the x-direction **3904**.

Further illustrated by FIG. **39**B, a one dimensional multi-element array forms an image as depicted in arrangement **3912**. A one-dimensional array with an elevation axis **3910**, in a y-direction **3914**, forms the ultrasound image **3914**, on the x-axis **3904**, z-axis **3906**, plane. A one-dimensional array with the elevation axis **3910**, in the x-direction **3904**, forms the ultrasound image **3914**, on the y-axis **3902**, z-axis **3906**. A one dimensional transducer array with elevation axis **3910**, along a y-axis **3902**, and polarization axis **3908**, along a z-axis **3906**, will result in a ultrasound image **3914**, formed along the x **3904** and the z **3906** plane. An alternate embodiment illustrated by FIG. **39**C depicts a one-dimensional transducer array with an elevation axis **3920**, in a x-axis **904**, and a polarization axis **3922**, in the z-axis **3906**, direction. The ultrasound image **3924**, is formed on the y **3902** and the z **3906** plane.

FIG. **40** illustrates the operation of a bi-plane image forming xy-probe where array **4012** has a high voltage applied for forming images. High voltage driving pulses **4006**, **4008**, **4010**, may be applied to the bottom array **4004**, with a y-axis elevation. This application may result in generation of transmission pulses for forming the received image on the XZ plane, while keeping the elements of the top array **4002** at a grounded level. Such probes enable a 3D imaging mode using simpler electronics than a full 2D transducer array. A touchscreen activated user interface as described herein can employ screen icons and gestures to actuate 3D imaging operations. Such imaging operations can be augmented by software running on the tablet data processor that processes the image data into 3D ultrasound images. This image processing software can employ filtering smoothing and/or interpolation operations known in the art. Beamsteering can also be used to enable 3D imaging operations. A preferred embodiment uses a plurality of 1D sub-array transducers arranged for bi plane imaging.

FIG. **41** illustrates the operation of a bi-plane image forming xy-probe. FIG. **41** illustrates a array **4110**, that has a high voltage applied to it for forming images. High voltage pulses **4102**, **4104**, **4106**, may be applied to the top array **4112**, with elevation in the x-axis, generating transmission pulses for forming the received image on the yz-plane, while keeping the elements of the bottom array **4014**, grounded **4108**. This embodiment can also utilize orthogonal 1D transducer arrays operated using sub-array beamforming as described herein.

FIG. **42** illustrates the circuit requirements of a bi-plane image forming xy-probe. The receive beamforming requirements are depicted for a bi-plane probe. A connection to receive the electronics **4202**, is made. Then elements from the select bottom array **4204**, and select top array **4208**, are connected to share one connect to the receive electronics **4202** channel. A two to one mux circuit can be integrated on the high voltage driver **4206**, **4210**. The two to one multiplexor circuit can be integrated into high voltage driver **4206**, **4212**. One receive beam is formed for each transmit beam. The bi-plane system requires a total of 256 transmit beams for which 128 transmit beams are used for forming a XZ-plane image and the other 128 transmit beams are used for forming a YZ-plane image. A multiple-received beam forming technique can be used to improve the frame rate. An ultrasound system with dual received beam capabilities for each transmit beam provides a system in which two received beams can be formed. The bi-plane probe only needs a total of 128 transmit beams for forming the two orthogonal plane images, in which 64 transmit beams are used to form a XZ-plane image with the other 64 transmit beams for the YZ-plane image. Similarly, for an ultrasound system with a quad or 4 receive beam capability, the probe requires 64 transmit beams to form two orthogonal-plane images.

FIGS. **43**A-**43**B illustrate an application for simultaneous bi-plane evaluation. The ability to measure the LV mechanical dyssynchrony with echocardiograph can help identify patients that are more likely to benefit from Cardiac Resynchronization Therapy. LV parameters needed to be quantified are Ts-(lateral-septal), Ts-SD, Ts-peak, etc. The Ts-(lateral-septal) can be measured on a 2D apical 4-chamber view Echo image, while the Ts-SD, Ts-peak (medial), Ts-onset (medial), Ts-peak(basal), Ts-onset (basal) can be obtained on two separated parasternal short-axis views with 6 segments at the level of mitral valve and at the papillary muscle level, respectively, providing a total of 12 segments. FIG. **43**A-**43**B depicts an xy-probe providing apical four chamber **4304**, and apicial two chamber **4302** images, to be viewed simultaneously.

FIGS. **44**A-**44**B illustrate ejection fraction probe measurement techniques. The biplane-probe provides for EF measurement, as visualization of two orthogonal planes ensure on-axis views are obtained. Auto-border detection algorithm, provides quantitative Echo results to select implant responders and guide the AV delay parameter setting. As depicted in FIG. **44** A XY probe acquires real-time simultaneous images from two orthogonal planes and the images **4402**, **4404** are displayed on a split screen. A manual contour tracing or automatic boarder tracing technique can be used to trace the endocardial boarder at both end-systole and end-diastolic time from which the EF is calculated. The LV areas in the apical 2CH **4402**, and 4CH **4404**, views, A1 and A2 respectively, are measured at the end of diastole and the end of systole. The LVEDV, left ventricular end-diastolic volume, and LVESV, left ventricular the end-systole volume, are calculated using the formula:

$$V = \frac{8}{3\pi}\frac{A_1 A_2}{L}.$$

And the ejection fraction is calculated by

$$EF = \frac{LVEDV - LVESD}{LVEDV}.$$

It is noted that the operations described herein are purely exemplary, and imply no particular order. Further, the operations can be used in any sequence, when appropriate, and/or can be partially used. Exemplary flowcharts are provided herein for illustrative purposes and are non-limiting examples of methods. One of ordinary skill in the art will recognize that exemplary methods may include more or fewer steps than those illustrated in the exemplary flowcharts, and that the steps in the exemplary flowcharts may be performed in a different order than shown.

In describing exemplary embodiments, specific terminology is used for the sake of clarity. For purposes of description, each specific term is intended to at least include all technical and functional equivalents that operate in a similar manner to accomplish a similar purpose. Additionally, in some instances where a particular exemplary embodiment includes a plurality of system elements or method steps, those elements or steps may be replaced with a single element or step. Likewise, a single element or step may be replaced with a plurality of elements or steps that serve the same purpose. Further, where parameters for various properties are specified herein for exemplary embodiments, those parameters may be adjusted up or down by ½0th, ⅒th, ⅕th, ⅓rd, ½, etc., or by rounded-off approximations thereof, unless otherwise specified.

With the above illustrative embodiments in mind, it should be understood that such embodiments can employ various computer-implemented operations involving data transferred or stored in computer systems. Such operations are those requiring physical manipulation of physical quantities. Typically, though not necessarily, such quantities take the form of electrical, magnetic, and/or optical signals capable of being stored, transferred, combined, compared, and/or otherwise manipulated.

Further, any of the operations described herein that form part of the illustrative embodiments are useful machine operations. The illustrative embodiments also relate to a device or an apparatus for performing such operations. The apparatus can be specially constructed for the required purpose, or can incorporate general-purpose computer devices selectively activated or configured by a computer program stored in the computer. In particular, various general-purpose machines employing one or more processors coupled to one or more computer readable media can be used with computer programs written in accordance with the teachings disclosed herein, or it may be more convenient to construct a more specialized apparatus to perform the required operations.

The foregoing description has been directed to particular illustrative embodiments of this disclosure. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their associated advantages. Moreover, the procedures, processes, and/or modules described herein may be implemented in hardware, software, embodied as a computer-readable medium having program instructions, firmware, or a combination thereof. For example, one or more of the functions described herein may be performed by a processor executing program instructions out of a memory or other storage device.

It will be appreciated by those skilled in the art that modifications to and variations of the above-described systems and methods may be made without departing from the inventive concepts disclosed herein. Accordingly, the disclosure should not be viewed as limited except as by the scope and spirit of the appended claims.

The invention claimed is:

1. A handheld medical ultrasound imaging device comprising:

a transducer probe housing a transducer array; and

a tablet housing powered by a battery, the housing having a front panel, a computer in the tablet housing, the computer including at least one processor and at least one memory, a touch screen display that displays an ultrasound image and a graphical user interface having a plurality of touch actuated icons, the touch screen display positioned on the front panel, and an ultrasound beamformer processing circuit disposed in the tablet housing that receives image signals from the transducer array, the touch screen display and the ultrasound beamformer processing circuit being communicably connected to the computer, the computer being configured to respond to a first input from the touch screen display to alter an operation of the ultrasound beamformer processing circuit to display an ultrasound image, a second input from the touch screen display actuating a needle guide operation such that a needle can be visualized with an image on the touch screen display, a third input from the touch screen display that actuates an imaging depth control adjustment with a touch gesture, and a fourth input from the touch screen display that actuates split screen viewing of the ultrasound image and a second diagnostic image on the touch screen display.

2. The device of claim **1** wherein the first input corresponds to a moving gesture on the touch screen display.

3. The device of claim **1** wherein the transducer array comprises a bi plane transducer array.

4. The device of claim **3** further comprising a second input that includes a double tap gesture against the touch screen display.

5. The device of claim **3** further comprising in response to the second input from the touch screen display, displaying a first cursor inside a region of a virtual window displaying a magnified image.

6. The device of claim **5** further comprising receiving, at the computer, a fifth input from the touch screen display, the fifth input being received inside the region of the virtual window.

7. The device of claim **6** wherein the fifth input corresponds to a drag gesture on the touch screen display.

8. The device of claim **6** further comprising in response to the fifth input from the touch screen display, moving the first cursor to a first location inside the region of the virtual window.

9. The device of claim **8** further comprising receiving, at the computer, a sixth input from the touchscreen display, the sixth input being received at the first location inside the region of the virtual window.

10. The device of claim **6** further comprising in response to the fifth input from the touch screen display, fixing the first cursor at the first location inside the region of the virtual window.

11. The device of claim **10** further comprising performing, by the computer, at least one measurement on the ultrasound image based at least in part on the first cursor at the first location.

12. The device of claim **1** further comprising a further input that corresponds to a double tap gesture against the touchscreen display.

13. The device of claim **10** wherein the computer receives a further input from the touchscreen display, the further input being received inside the region of the virtual window.

14. The device of claim **13** wherein the further input corresponds to a press and drag gesture against the touch screen display.

15. The device of claim **13** further comprising in response to the further input from the touch screen display connecting a line on the touch screen display extending from the first cursor across at least a portion of the ultrasound image to a second location inside the region of the virtual window.

16. The device of claim **1** wherein the wherein the housing has a volume of less than 2500 cubic centimeters.

17. The device of claim **1** wherein the housing is connected to a stand.

18. The device of claim **17** wherein the stand rotates relative to the housing.

19. The device of claim **1** wherein the housing mounts on a cart.

20. The device of claim **1** wherein a multiplexor on the cart can electrically connect to the tablet housing to connect to a plurality of transducer arrays.

21. The device of claim **17** wherein the housing docks with the stand.

22. The device of claim **21** wherein the stand housing is electrically connected to the stand and wherein the stand has external communication parts.

23. The device of claim **20** wherein the multiplexor can be switched using a touch gesture.

24. The device of claim **1**, wherein the ultrasound image includes an image of a portion of a patient's body.

25. The device of claim **1**, further comprising a needle guide to position the needle with respect to a portion of the patient's body.

26. The device of claim **1**, wherein the touch screen display further displays a visualization of the needle in a split screen format.

27. The device of claim **1**, wherein the touch screen further displays an image of the needle within a patient's body.

28. The device of claim **1**, wherein the touch screen display further displays at least one needle visualization touch control.

29. The device of claim **1**, wherein the at least one needle visualization touch control is configured to guide the needle during a needle injection.

30. The device of claim **1**, wherein the at least one needle visualization touch control includes controlling the dynamic range or performing a desired map operation.

31. The device of claim **1**, wherein the at least one needle visualization touch control includes at least one of a press gesture, or a press and drag gesture.

32. The device of claim **1**, further comprising a needle position sensing system.

33. The device of claim **32**, wherein the needle position sensing system includes a passive ultrasound transducer element.

34. The device of claim **32**, wherein the needle position sensing system includes at least one ultrasound transducer element operatively coupled to a needle guide.

35. The device of claim **32**, wherein the needle position sensing system includes an ultrasound imaging probe assembly.

36. The device of claim **1**, further comprising a needle guide mounted to the ultrasound imaging probe assembly via a needle guide mounting bracket.

37. The device of claim **32**, wherein the needle position sensing system includes an ultrasound reflector configured to reflect ultrasonic waves.

38. The device of claim **37**, wherein the ultrasound reflector is operatively coupled to the needle.

39. The device of claim **37**, wherein the ultrasound reflector is operatively coupled to an exposed end of the needle.

40. The device of claim **37**, wherein a position of the ultrasound reflector is determined by transmitting an ultrasonic wave from a transducer element on a needle guide.

41. The device of claim **37**, wherein the ultrasound reflector is configured to reflect the ultrasonic wave back to the transducer element.

42. The device of claim **37**, wherein a distance between the ultrasound reflector and the transducer element is calculated based on a time delay of the reflected ultrasonic wave.

43. The device of claim **32**, wherein the needle position sensing system includes a needle guide and transducer elements enclosed in an enclosure of an imaging probe.

44. The device of claim **32**, wherein the needle position sensing system includes a linear ultrasound array mounted substantially parallel to a direction of movement of the needle.

45. A method of operating a handheld medical ultrasound imaging device, the medical ultrasound imaging device comprising a transducer probe, a tablet housing, the tablet housing having a front panel, a computer in the housing, the computer including at least one processor and at least one memory, a touch screen display that displays an ultrasound image, the image being adjustable in response to an imaging depth control touch gesture and that displays a split screen icon such that the touch screen can operate in a split screen format to display the ultrasound image and a second diagnostic image, the touch screen display positioned on the front panel, and an ultrasound beamformer processing circuit disposed in the tablet housing that is powered by a battery, the touch screen display and the ultrasound beamformer processing circuit being communicably coupled to the computer, the method comprising the steps of:

receiving, at the computer, a first input from the touch screen display to actuate a needle guide operation; and

in response to a second input from the touch screen display, operating the ultrasound beamformer processing circuit to image a needle inserted into a patient.

46. The method of claim **45** further comprising a further input corresponding to a moving gesture on the touch screen display.

47. The method of claim **45** further comprising receiving, at the computer, a third input from the touch screen display that corresponds to a double tap gesture against the touch screen display.

48. The method of claim **45** wherein a third input corresponds to a drag gesture on the touch screen display.

49. The method of claim **48** further comprising in response to the third input from the touch screen display, moving the first cursor to a first location inside the region of a virtual window.

50. The method of claim **49** further comprising receiving, at the computer, a fourth input from the touchscreen display, the fourth input being received at the first location inside the region of the virtual window.

51. The method of claim **45** wherein a third input corresponds to a press gesture against the touch screen display.

52. The method of claim **45** further comprising receiving, at the computer, a second further input from the touchscreen display, the second further input being received substantially simultaneously with the further input.

53. The method of claim **45** wherein the second further input corresponds to a tap gesture against the touchscreen display.

54. The method of claim **45** wherein a third input corresponds to a double tap gesture against the touchscreen display.

55. The method of claim **54** further comprising in response to the third further input from the touch screen display, displaying a second cursor at a second location inside the region of a virtual window.

56. The method of claim **55** further comprising performing, by the computer, at least one measurement on the ultrasound image based at least in part on the respective locations of the first and second cursors inside the region of the virtual window.

57. The method of claim **55** further comprising receiving, at the computer, a fourth further input from the touch screen display, the fourth further input being received inside the region of the virtual window.

58. The method of claim **57** wherein the fourth further input corresponds to a press and drag gesture against the touch screen display.

59. The method of claim **57** further comprising in response to the fourth further input from the touch screen display, providing a connecting line on the touch screen display extending from the first cursor across at least a portion of the ultrasound image to a second location inside the region of the virtual window.

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摘要(译)

示例性实施例提供用于便携式医学超声成像的系统和方优选实施例利用平板触摸屏显示器，其可操作以控制成像和显示操作，而无需使用传统的键盘或控制。某些实施例提供超声成像系统，其中扫描头包括执行远场子阵列波束成形的波束形成器电路或包括激励所选元件的稀疏阵列选择电路。示例性实施例还提供了包括一个或多个多芯片模块的超声引擎电路板，以及包括具有一个或多个多芯片模块的超声引擎电路板的便携式医疗超声成像系统。示例性实施例还提供了使用分级两阶段或三阶段波束形成系统的方法，三维超声图像可以实时生成。