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(54) **BRAIN STIMULATION AND SENSING**

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

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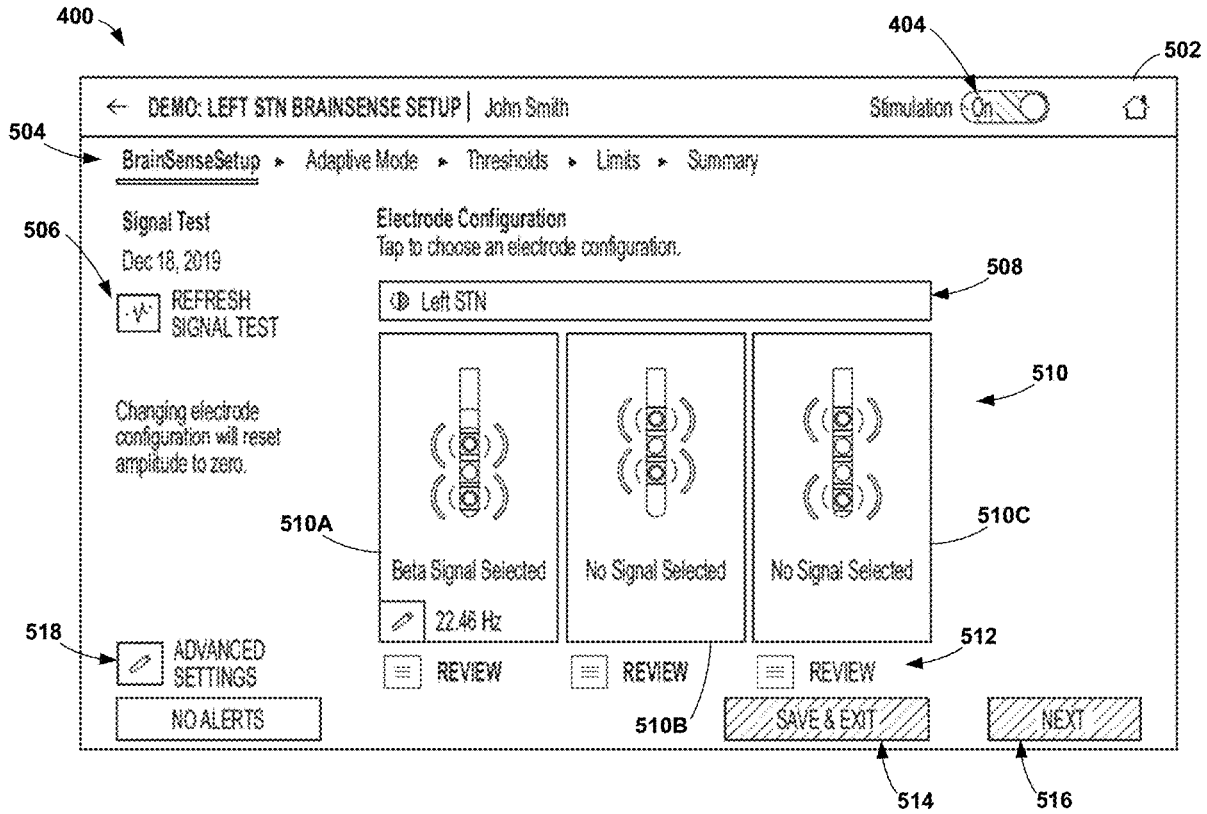
(57) **ABSTRACT**

Devices, systems, and techniques are disclosed for managing electrical stimulation therapy and/or sensing of physiological signals such as brain signals. For example, a system may assist a clinician in identifying one or more electrode combinations for sensing a brain signal. In another example, a user interface may display brain signal information and values of a stimulation parameter at least partially defining electrical stimulation delivered to a patient when the brain signal information was sensed.



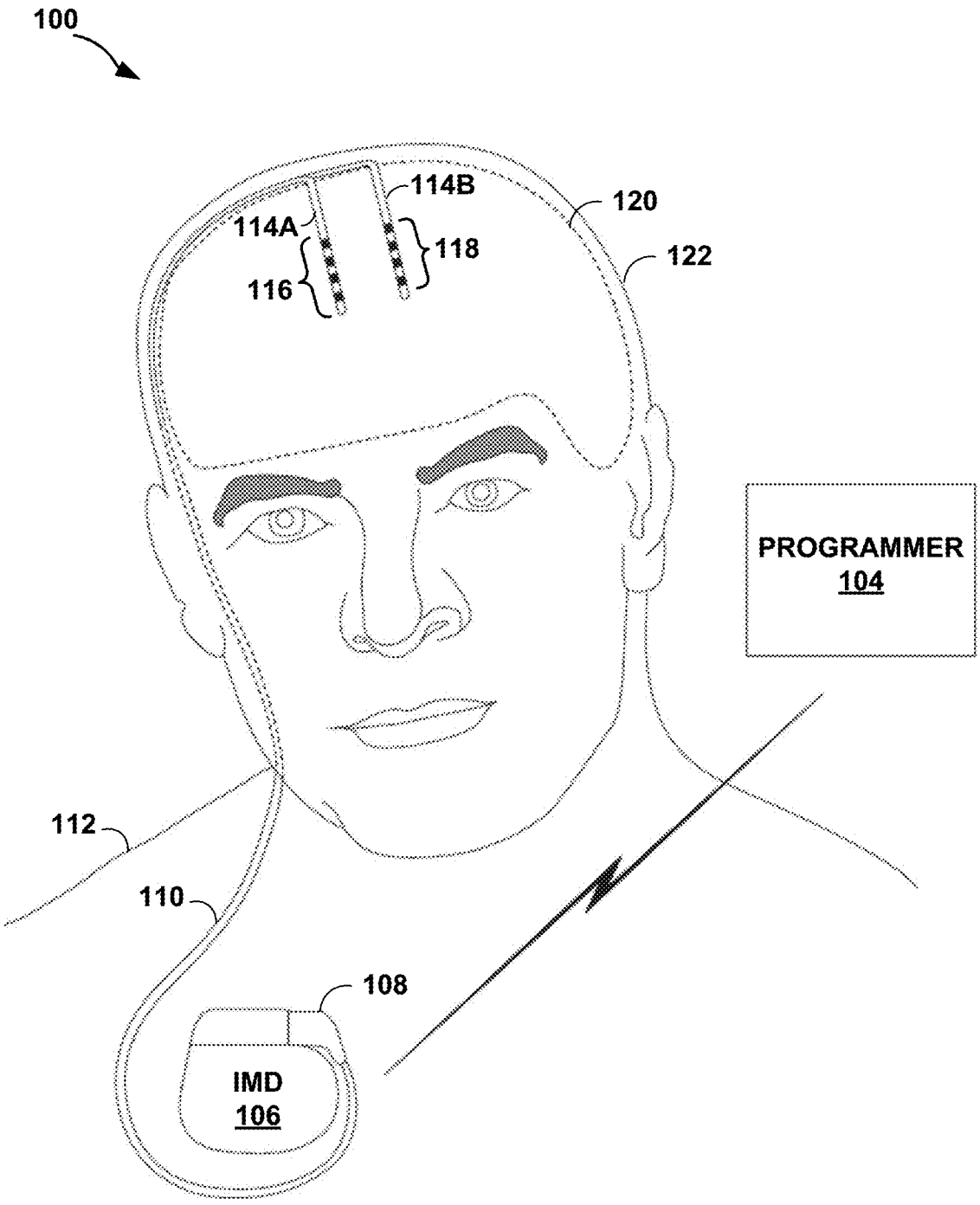

100
114B
120
114A
118
122
116
PROGRAMMER
104
112
110
108
IMD
106

FIG. 1

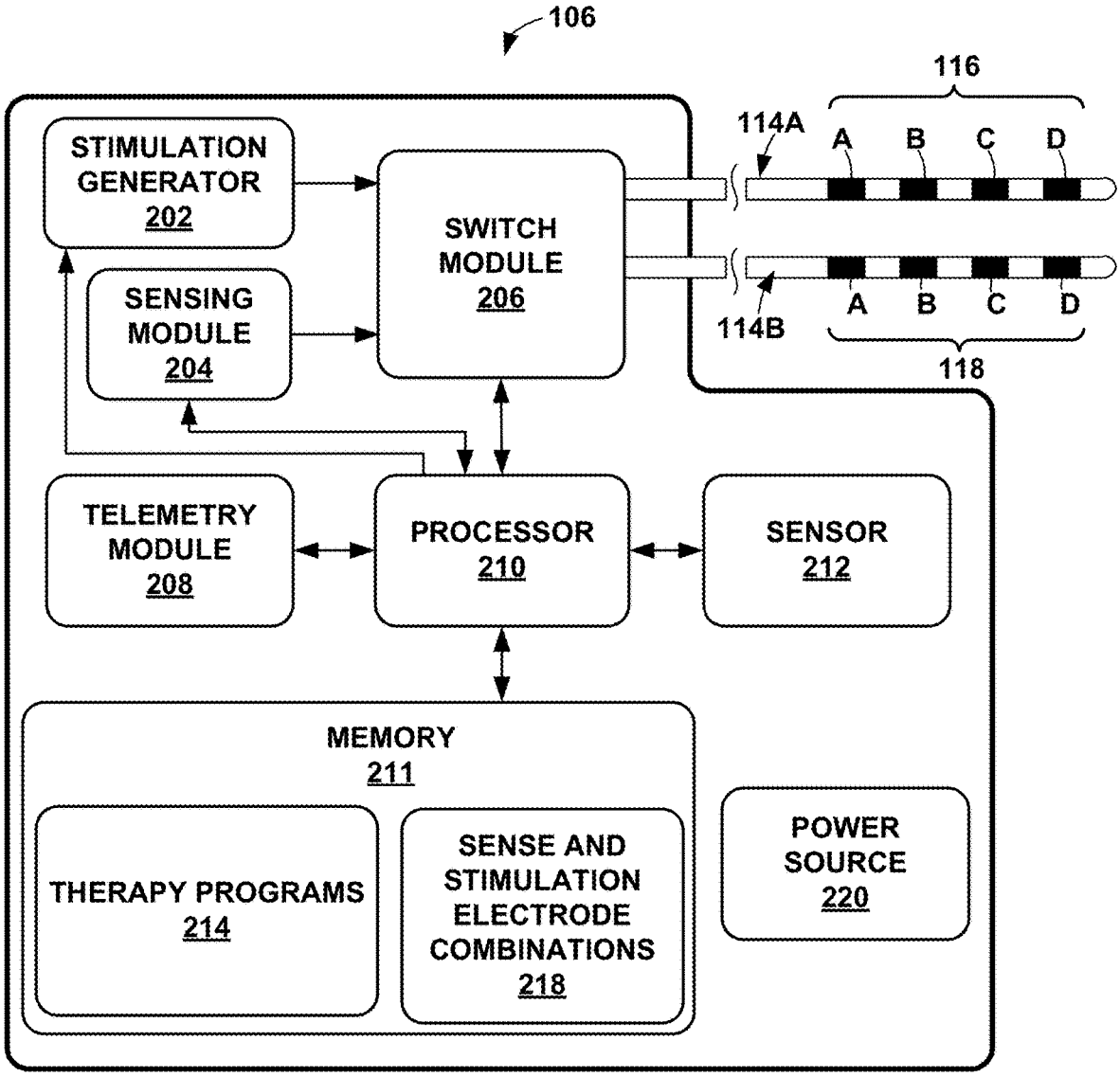

106
116
114A
A
B
C
D
STIMULATION GENERATOR 202
SWITCH MODULE 206
SENSING MODULE 204
114B
A
B
C
D
118
TELEMETRY MODULE 208
PROCESSOR 210
SENSOR 212
MEMORY 211
THERAPY PROGRAMS 214
SENSE AND STIMULATION ELECTRODE COMBINATIONS 218
POWER SOURCE 220

FIG. 2

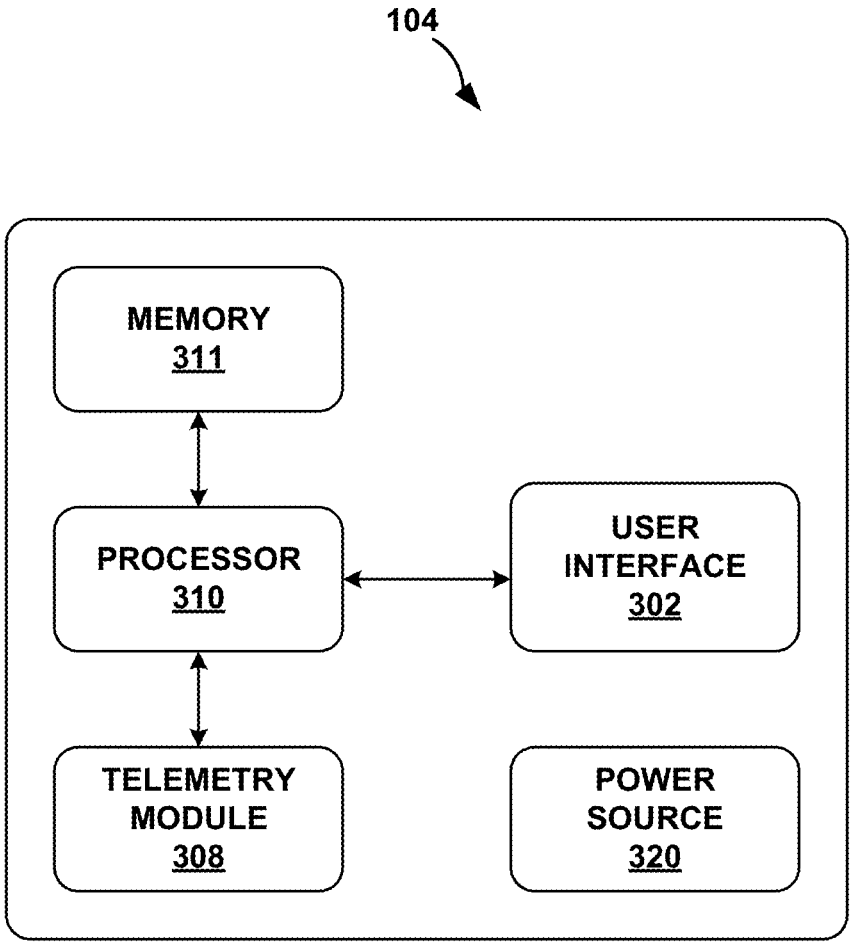

104
MEMORY
311
PROCESSOR
310
USER
INTERFACE
302
TELEMETRY
MODULE
308
POWER
SOURCE
320

FIG. 3

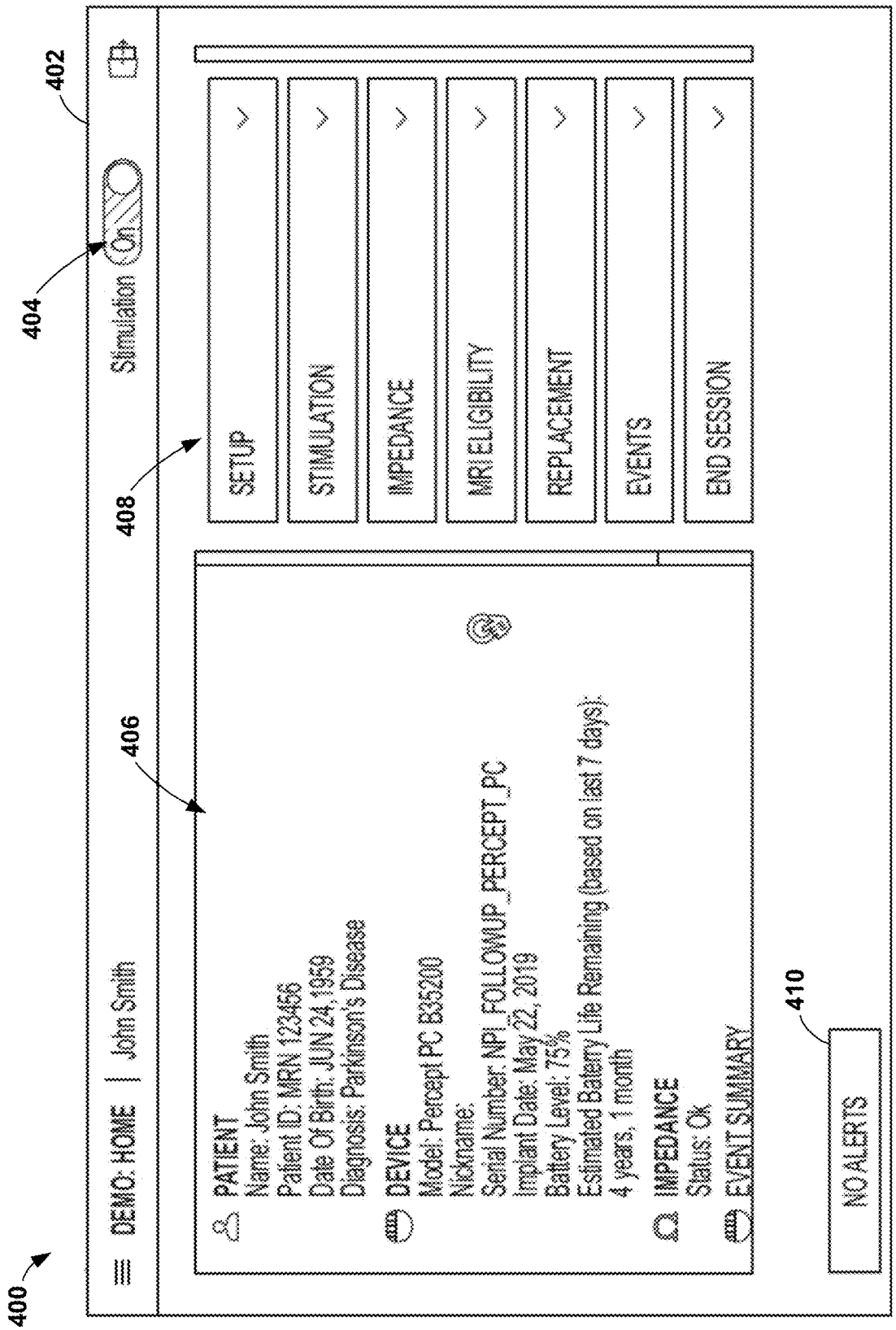

400
402
404
406
408
410
DEMO: HOME | John Smith
Stimulation
On
PATIENT
Name: John Smith
Patient ID: MRN 123456
Date Of Birth: JUN 24,1959
Diagnosis: Parkinson's Disease
DEVICE
Model: Percept PC B35200
Nickname:
Serial Number: NPI_FOLLOWUP_PERCEPT_PC
Implant Date: May 22, 2019
Battery Level: 75%
Estimated Battery Life Remaining (based on last 7 days):
4 years, 1 month
IMPEDANCE
Status: Ok
EVENT SUMMARY
NO ALERTS
SETUP
STIMULATION
IMPEDANCE
MRI ELIGIBILITY
REPLACEMENT
EVENTS
END SESSION

FIG. 4

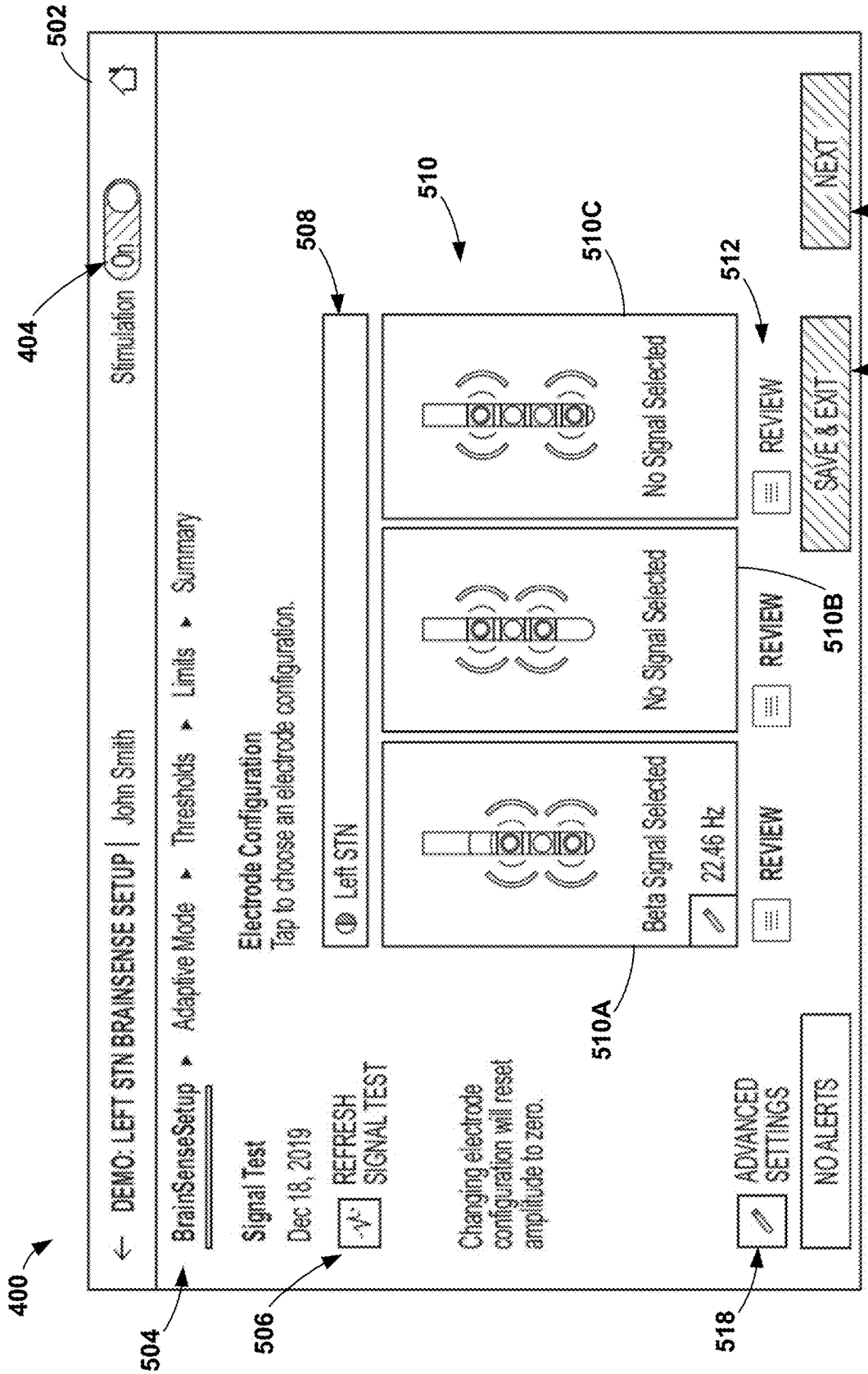

400
502
404
DEMO: LEFT STN BRAINSENSE SETUP | John Smith
Simulation ON OFF
BrainSenseSetup ▸ Adaptive Mode ▸ Thresholds ▸ Limits ▸ Summary
504
Signal Test
Dec 18, 2019
REFRESH SIGNAL TEST
506
Changing electrode configuration will reset amplitude to zero.
Electrode Configuration
Tap to choose an electrode configuration.
508
Left STN
510
510A
Beta Signal Selected
22.46 Hz
REVIEW
510B
No Signal Selected
REVIEW
510C
No Signal Selected
REVIEW
512
514
SAVE & EXIT
516
NEXT
518
ADVANCED SETTINGS
NO ALERTS

FIG. 5

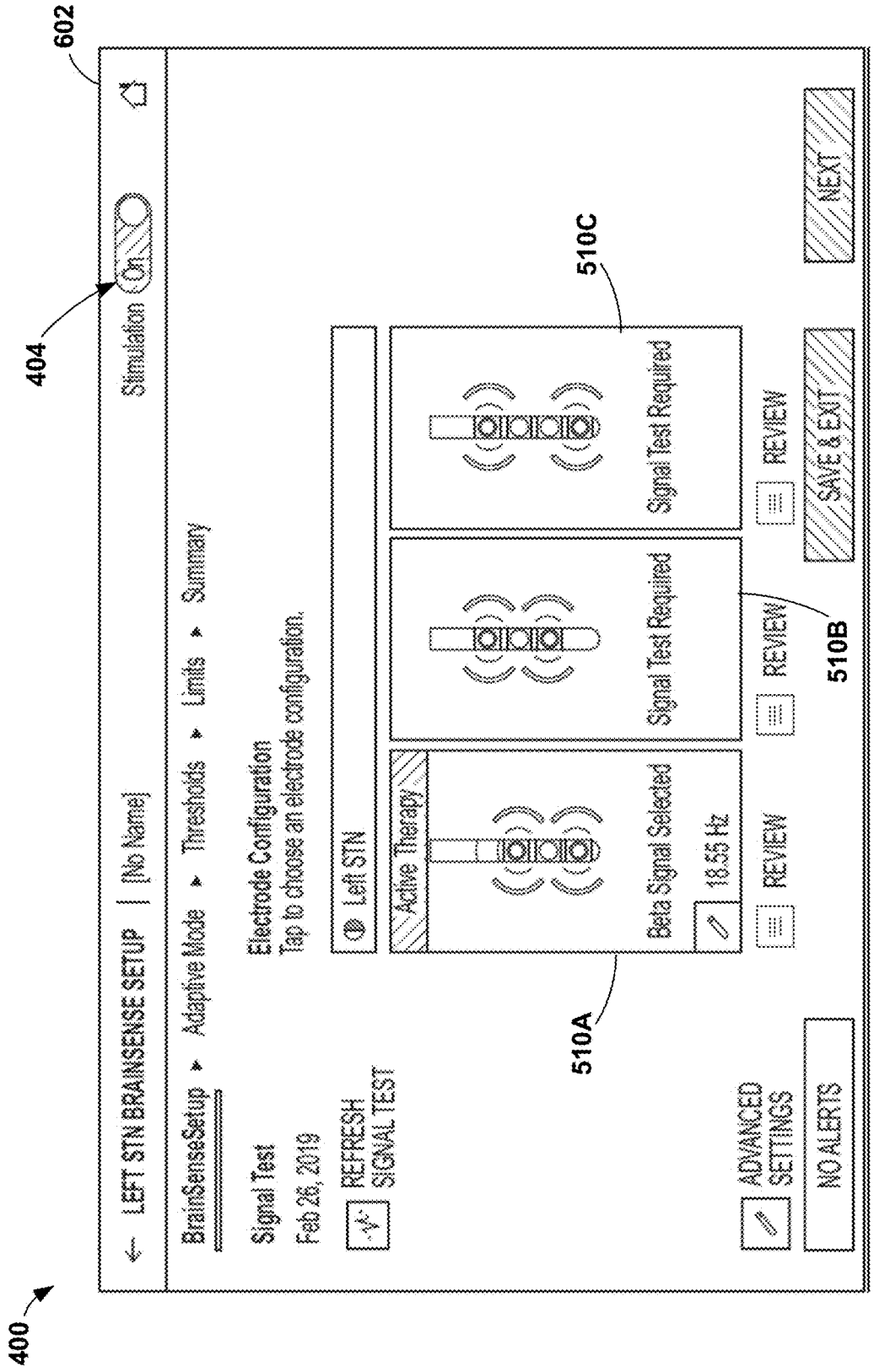

400
602
404
LEFT STN BRAINSENSE SETUP | [No Name]
Stimulation On
BrainSenseSetup ▸ Adaptive Mode ▸ Thresholds ▸ Limits ▸ Summary
Signal Test
Feb 26, 2019
REFRESH SIGNAL TEST
Electrode Configuration
Tap to choose an electrode configuration.
Left STN
Active Therapy
Beta Signal Selected
18.55 Hz
REVIEW
510A
Signal Test Required
REVIEW
510B
Signal Test Required
510C
REVIEW
SAVE & EXIT
NEXT
ADVANCED SETTINGS
NO ALERTS

FIG. 6

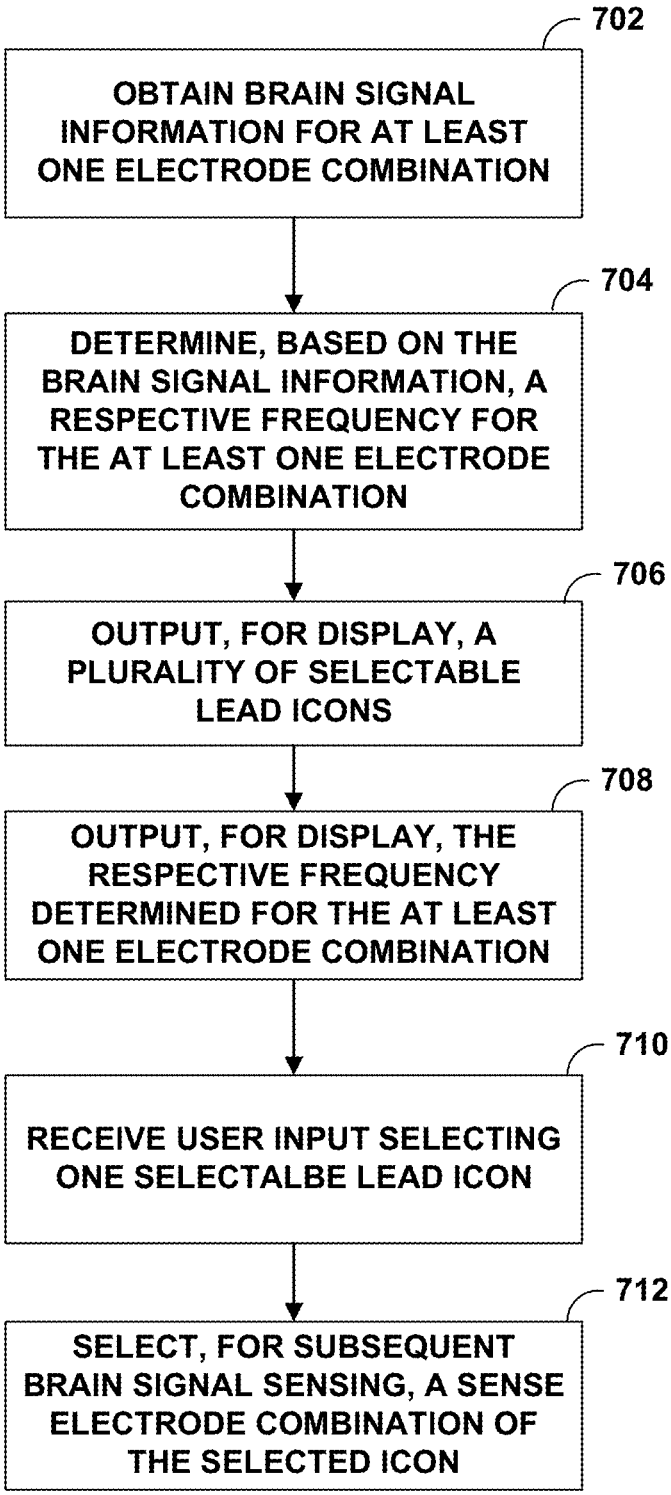

702
OBTAIN BRAIN SIGNAL INFORMATION FOR AT LEAST ONE ELECTRODE COMBINATION
704
DETERMINE, BASED ON THE BRAIN SIGNAL INFORMATION, A RESPECTIVE FREQUENCY FOR THE AT LEAST ONE ELECTRODE COMBINATION
706
OUTPUT, FOR DISPLAY, A PLURALITY OF SELECTABLE LEAD ICONS
708
OUTPUT, FOR DISPLAY, THE RESPECTIVE FREQUENCY DETERMINED FOR THE AT LEAST ONE ELECTRODE COMBINATION
710
RECEIVE USER INPUT SELECTING ONE SELECTALBE LEAD ICON
712
SELECT, FOR SUBSEQUENT BRAIN SIGNAL SENSING, A SENSE ELECTRODE COMBINATION OF THE SELECTED ICON

FIG. 7

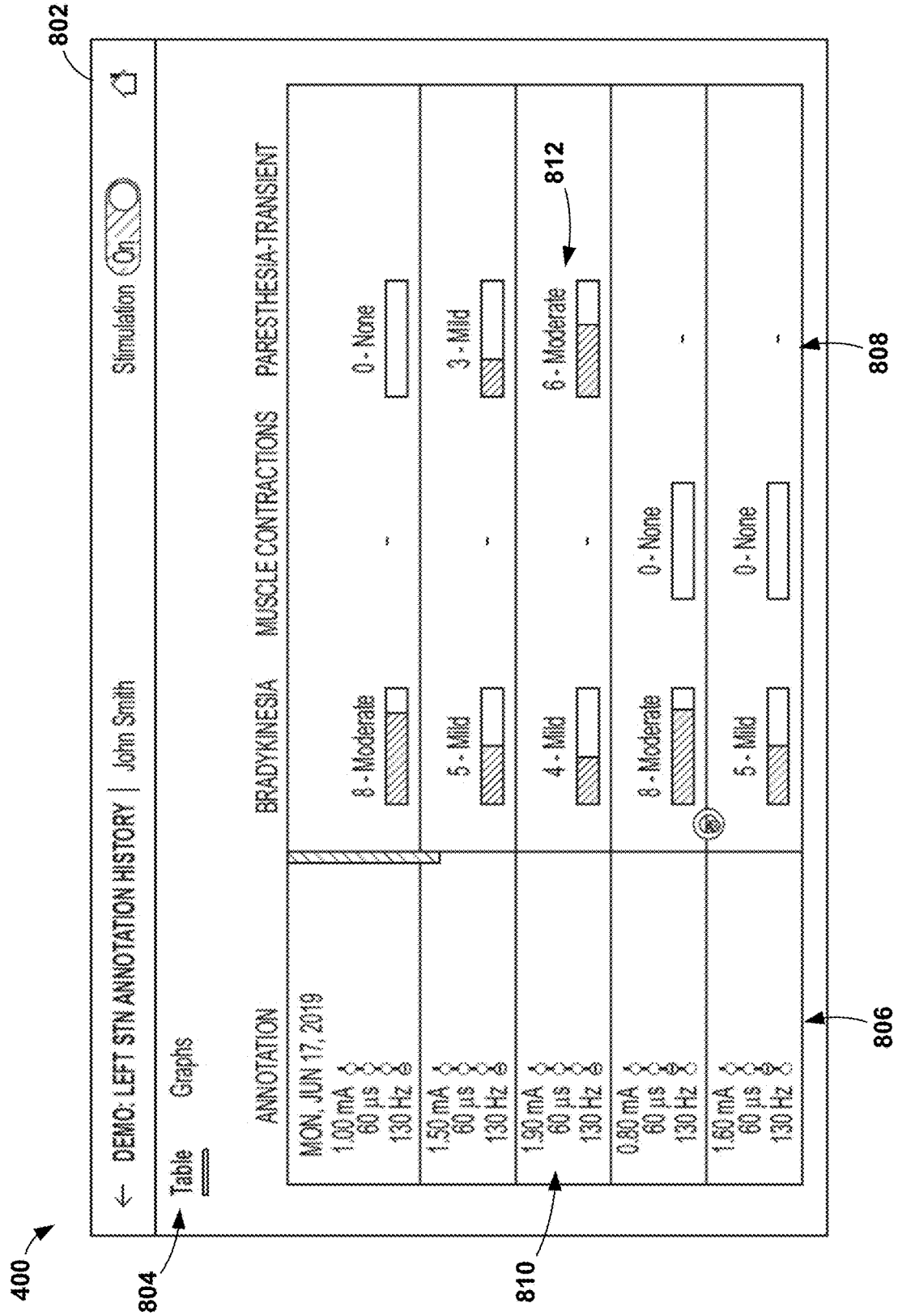

400
802
804
806
808
810
812
DEMO: LEFT STN ANNOTATION HISTORY | John Smith
Stimulation On
Table
Graphs
ANNOTATION
BRADYKINESIA
MUSCLE CONTRACTIONS
PARESTHESIA-TRANSIENT
MON, JUN 17, 2019
1.00 mA
60 µs
130 Hz
8 - Moderate
0 - None
1.50 mA
60 µs
130 Hz
5 - Mild
3 - Mild
1.90 mA
60 µs
130 Hz
4 - Mild
6 - Moderate
0.80 mA
60 µs
130 Hz
8 - Moderate
0 - None
1.60 mA
60 µs
130 Hz
5 - Mild
0 - None

FIG. 8

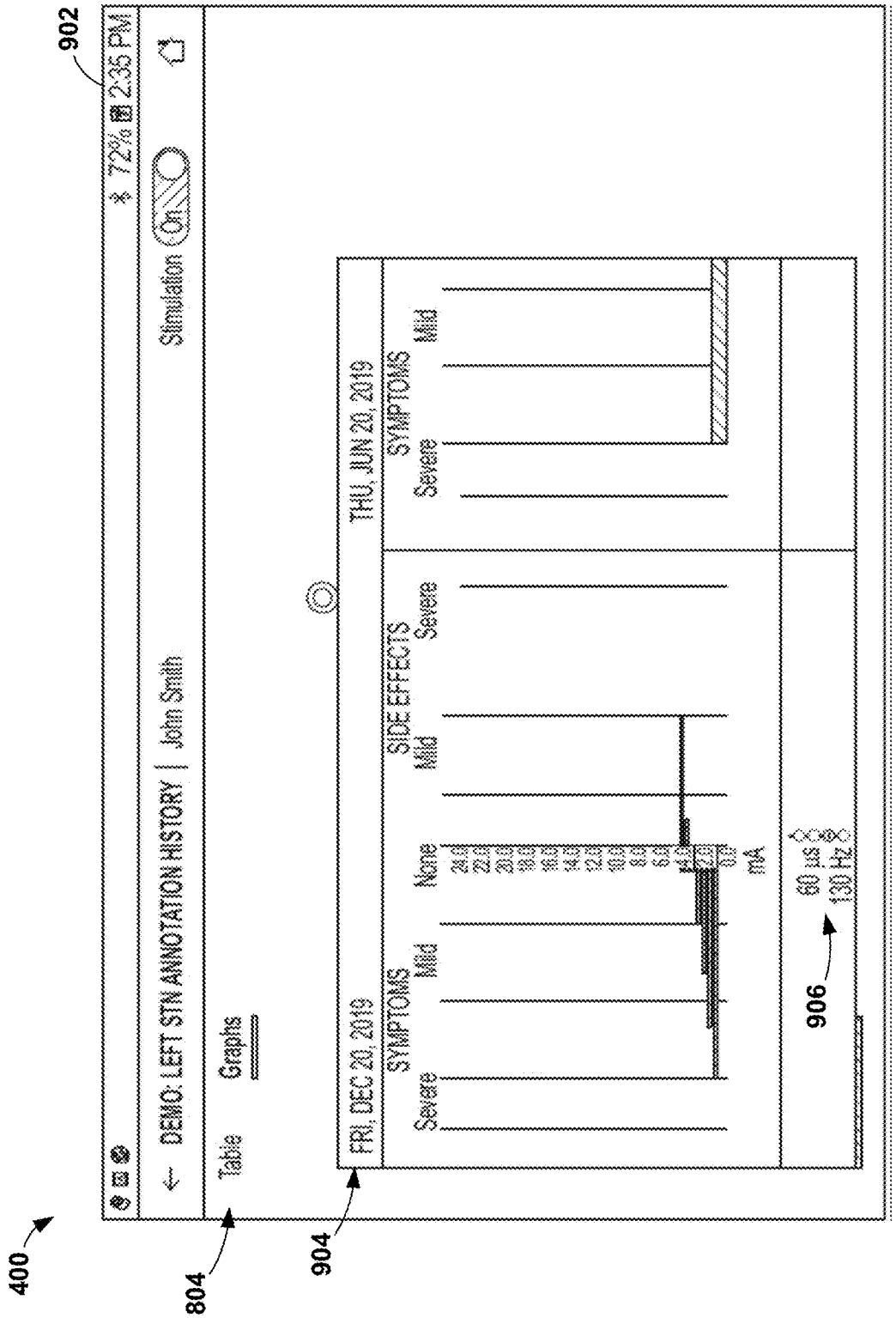

902
72% 2:35 PM
DEMO: LEFT STN ANNOTATION HISTORY | John Smith
Simulation
Table
Graphs
804
904
FRI, DEC 20, 2019
SYMPTOMS
Severe
Mild
None
SIDE EFFECTS
Mild
Severe
THU, JUN 20, 2019
SYMPTOMS
Severe
Mild
mA
60 µs
130 Hz
906
400

FIG. 9

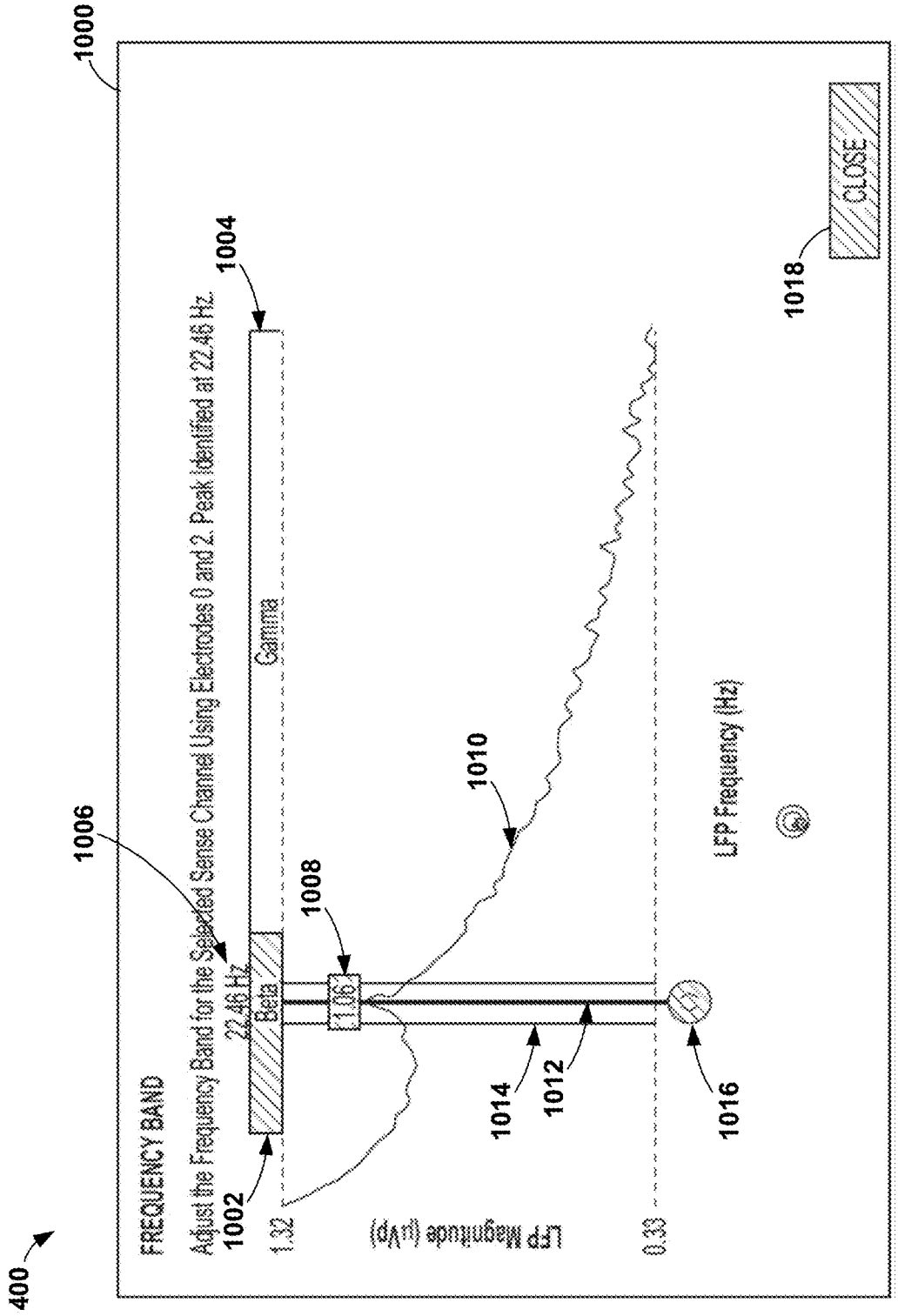

400
1000
FREQUENCY BAND
Adjust the Frequency Band for the Selected Sense Channel Using Electrodes 0 and 2. Peak Identified at 22.46 Hz.
1002
1004
1006
1008
1010
1012
1014
1016
1018
22.46 Hz
Beta
Gamma
1.06
1.32
0.33
LFP Magnitude (μVp)
LFP Frequency (Hz)
CLOSE

FIG. 10

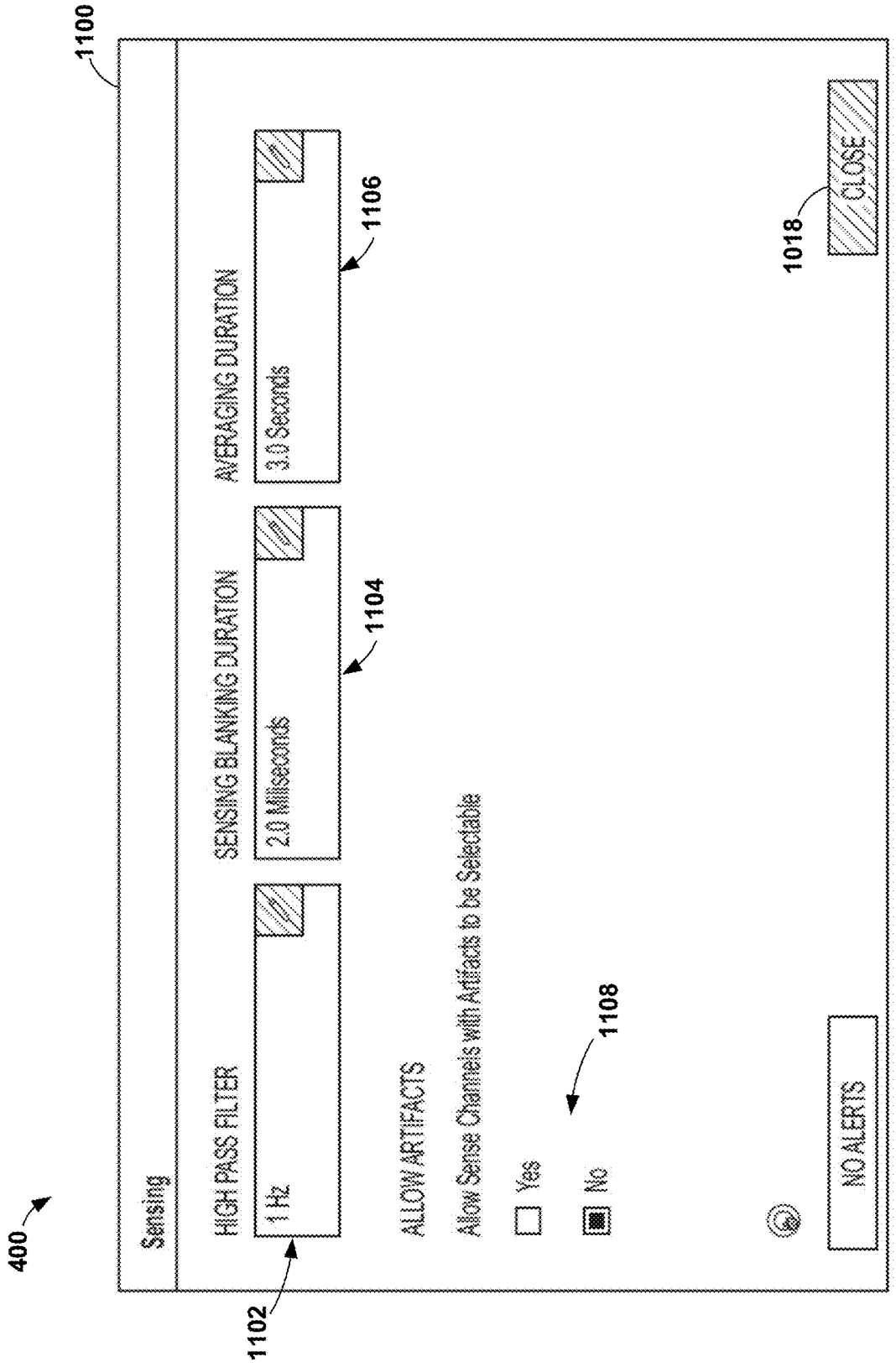

400
1100
Sensing
HIGH PASS FILTER
1 Hz
1102
SENSING BLANKING DURATION
2.0 Milliseconds
1104
AVERAGING DURATION
3.0 Seconds
1106
ALLOW ARTIFACTS
Allow Sense Channels with Artifacts to be Selectable
Yes
No
1108
NO ALERTS
1018
CLOSE

FIG. 11

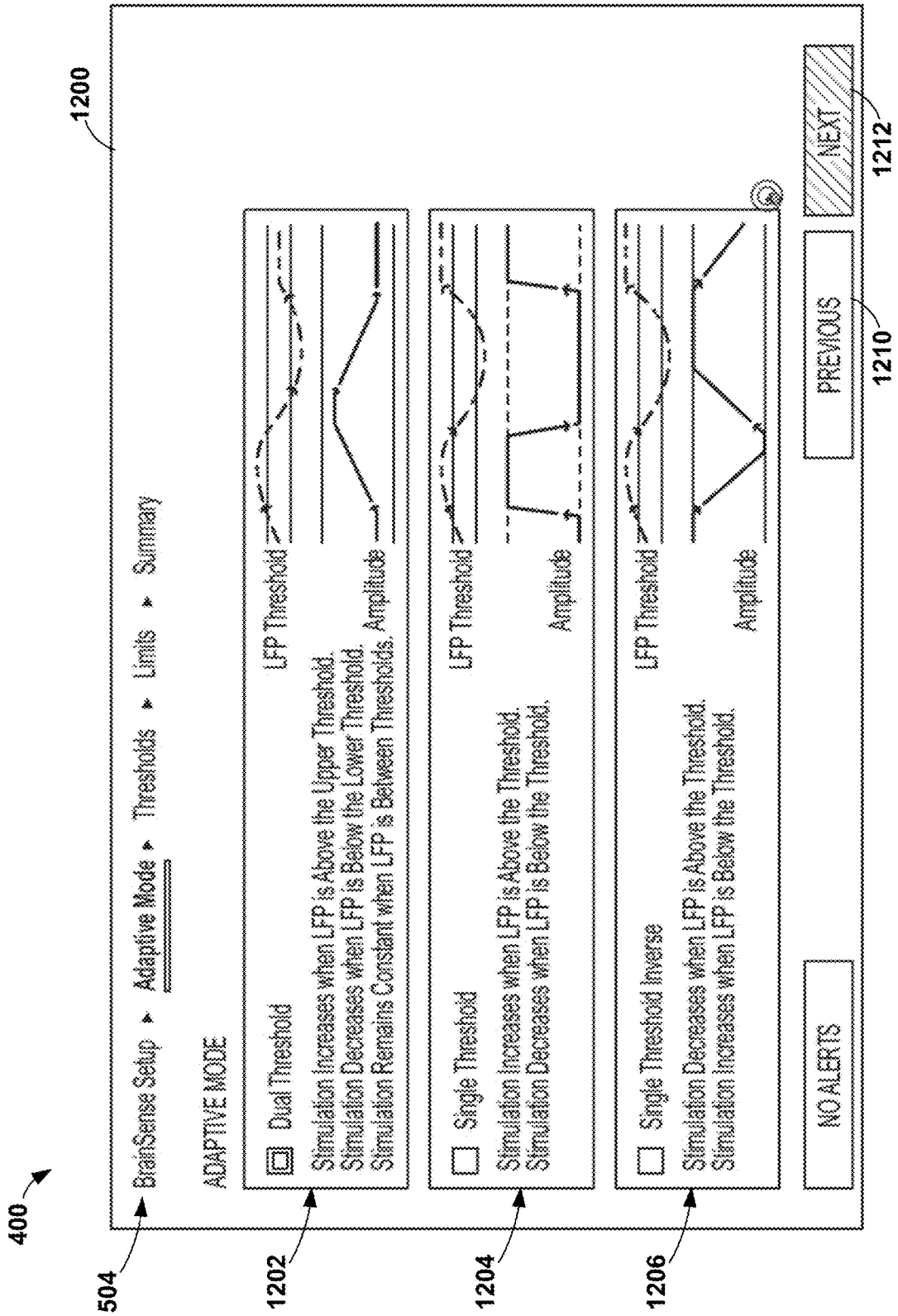

400
1200
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
ADAPTIVE MODE
Dual Threshold
Simulation Increases when LFP is Above the Upper Threshold.
Simulation Decreases when LFP is Below the Lower Threshold.
Simulation Remains Constant when LFP is Between Thresholds.
LFP Threshold
Amplitude
Single Threshold
Simulation Increases when LFP is Above the Threshold.
Simulation Decreases when LFP is Below the Threshold.
LFP Threshold
Amplitude
Single Threshold Inverse
Simulation Decreases when LFP is Above the Threshold.
Simulation Increases when LFP is Below the Threshold.
LFP Threshold
Amplitude
NO ALERTS
PREVIOUS
NEXT
504
1202
1204
1206
1210
1212

FIG. 12

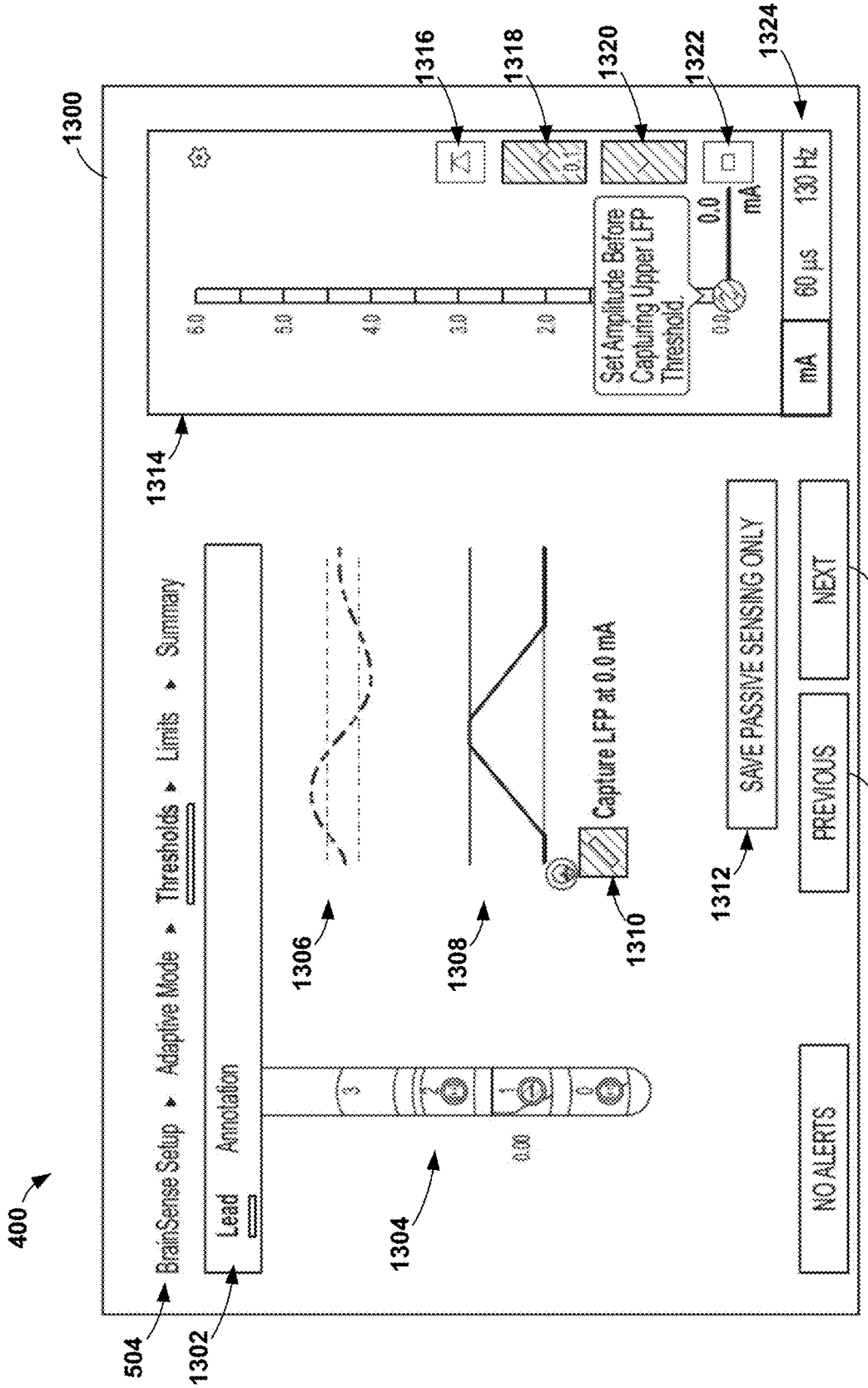

400
1300
1316
1318
1320
1322
1324
1314
6.0
5.0
4.0
3.0
2.0
Set Amplitude Before Capturing Upper LFP Threshold
0.0
mA
130 Hz
60 µs
mA
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
1306
1308
Capture LFP at 0.0 mA
1310
1312
SAVE PASSIVE SENSING ONLY
PREVIOUS
NEXT
1210
1212
NO ALERTS
1304
504
1302

FIG. 13

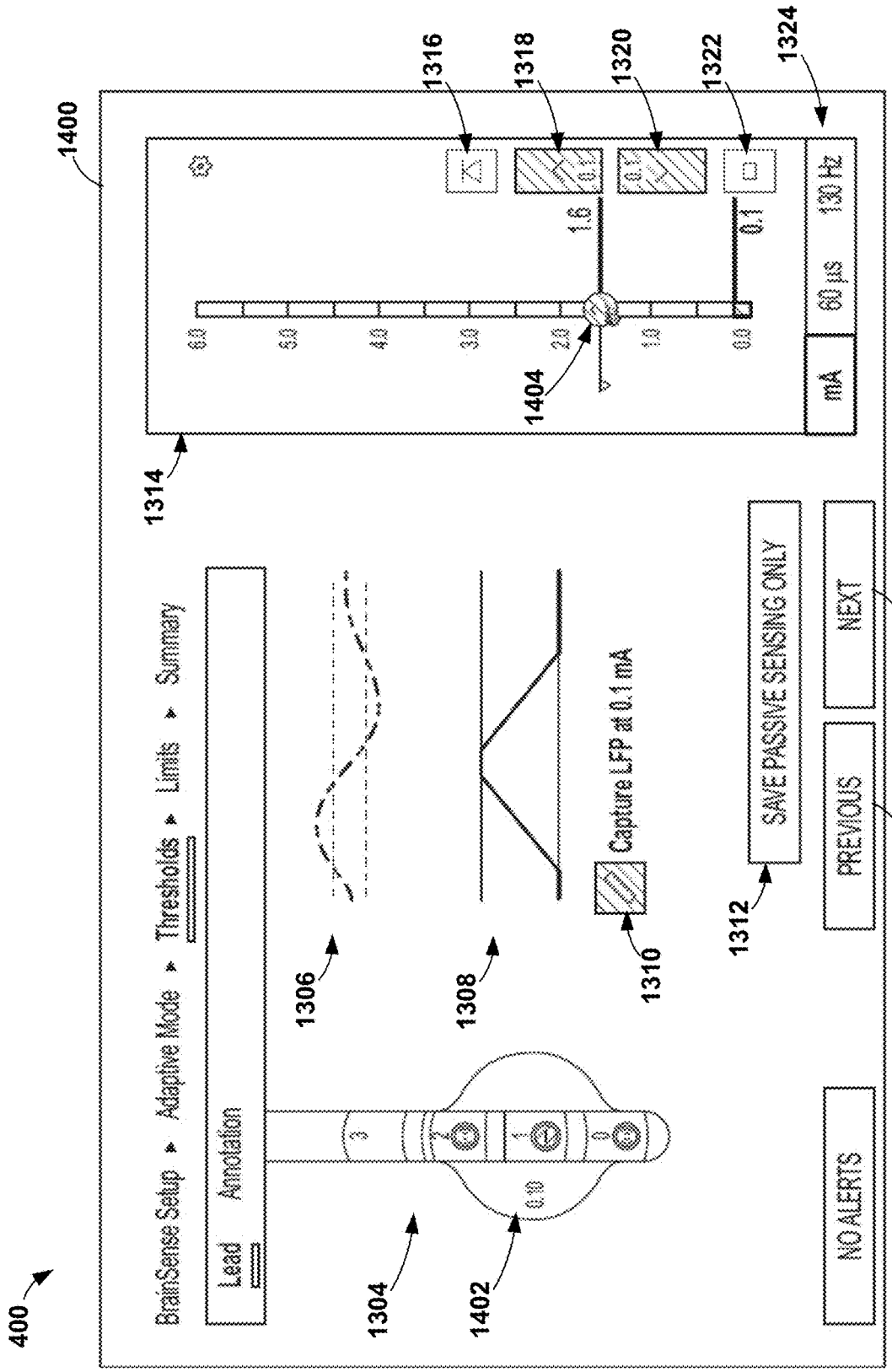

400
1400
1314
1316
1318
1320
1322
1324
1404
1.6
0.1
130 Hz
60 µs
mA
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
1306
1308
1310
Capture LFP at 0.1 mA
1312
SAVE PASSIVE SENSING ONLY
PREVIOUS
NEXT
1210
1212
NO ALERTS
1304
1402

FIG. 14

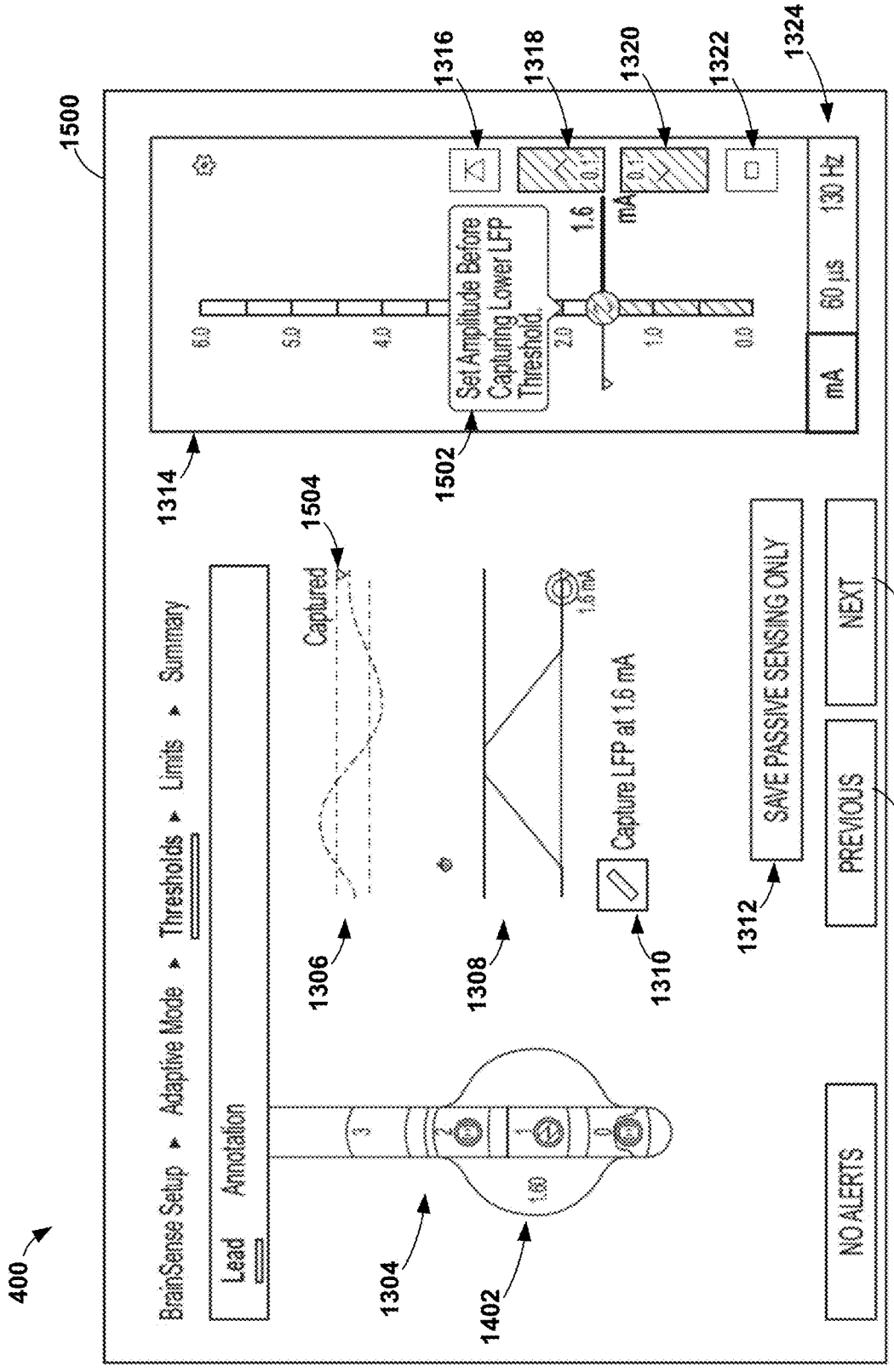

400
1500
1316
1318
1320
1322
1324
1314
1502
1504
1306
1308
1310
1312
1212
1210
1304
1402
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
Captured
Capture LFP at 1.6 mA
SAVE PASSIVE SENSING ONLY
NEXT
PREVIOUS
NO ALERTS
Set Amplitude Before Capturing Lower LFP Threshold.
1.6
mA
130 Hz
60 µs

FIG. 15

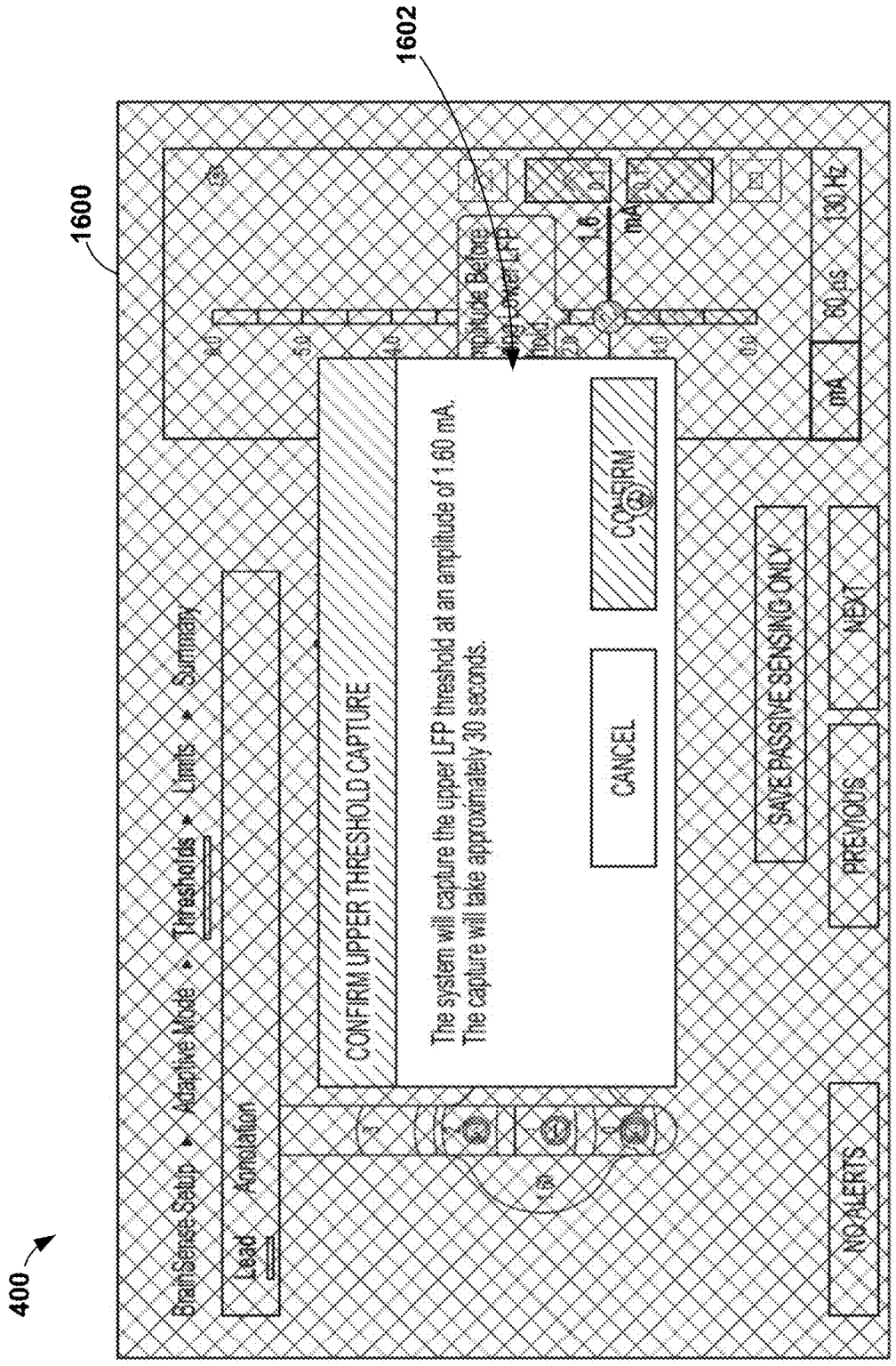

400
1600
1602
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
CONFIRM UPPER THRESHOLD CAPTURE
The system will capture the upper LFP threshold at an amplitude of 1.60 mA.
The capture will take approximately 30 seconds.
CANCEL
CONFIRM
SAVE PASSIVE SENSING ONLY
PREVIOUS
NEXT
NO ALERTS
mA
80 µs
130 Hz
1.6
mA

FIG. 16

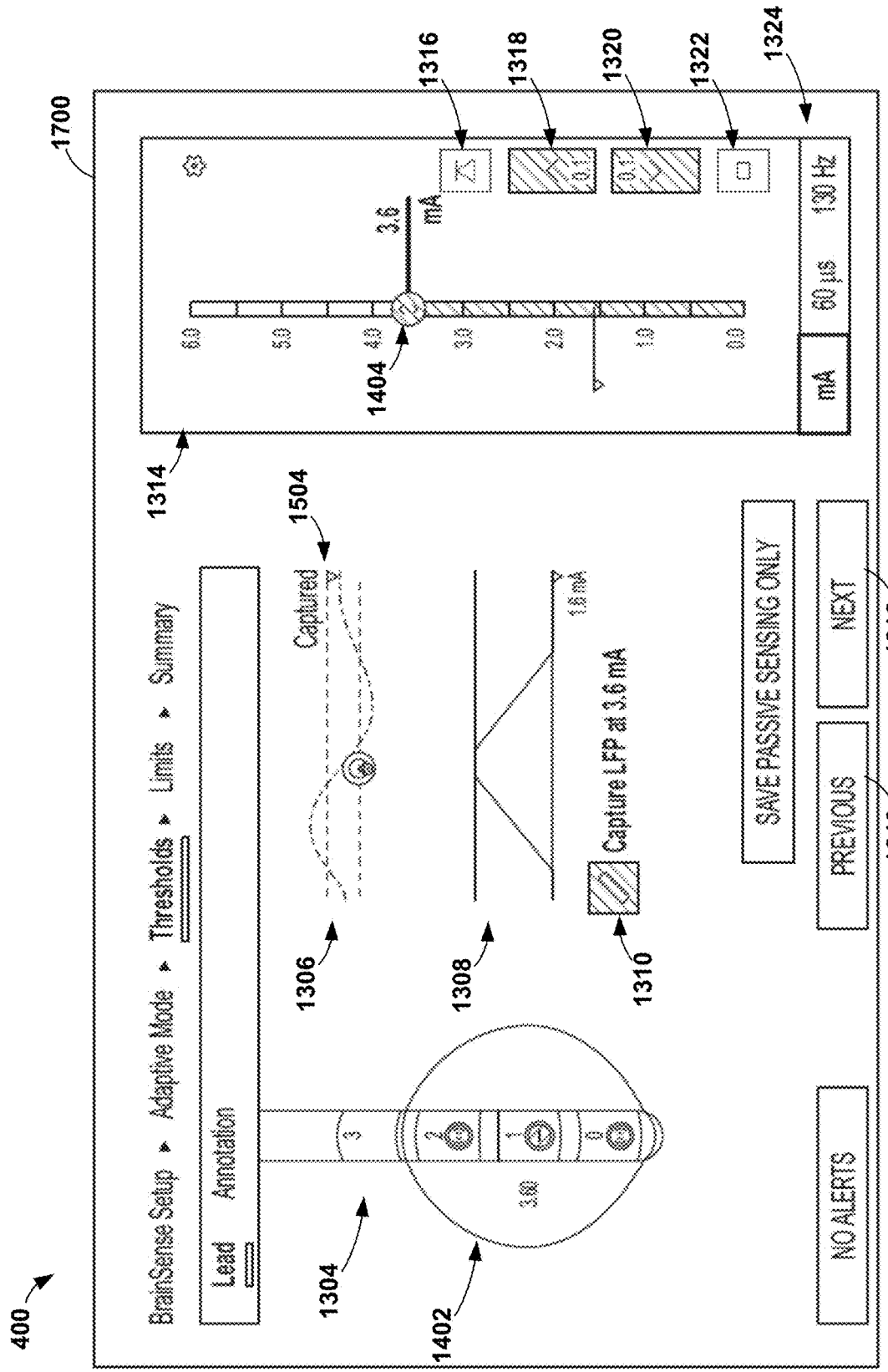

400
1700
1314
1316
1318
1320
1322
1324
3.6
mA
1404
6.0
5.0
4.0
3.0
2.0
1.0
0.0
mA
60 µs
130 Hz
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
1304
1402
1504
Captured
1306
1308
1.6 mA
Capture LFP at 3.6 mA
1310
SAVE PASSIVE SENSING ONLY
NEXT
1212
PREVIOUS
1210
NO ALERTS

FIG. 17

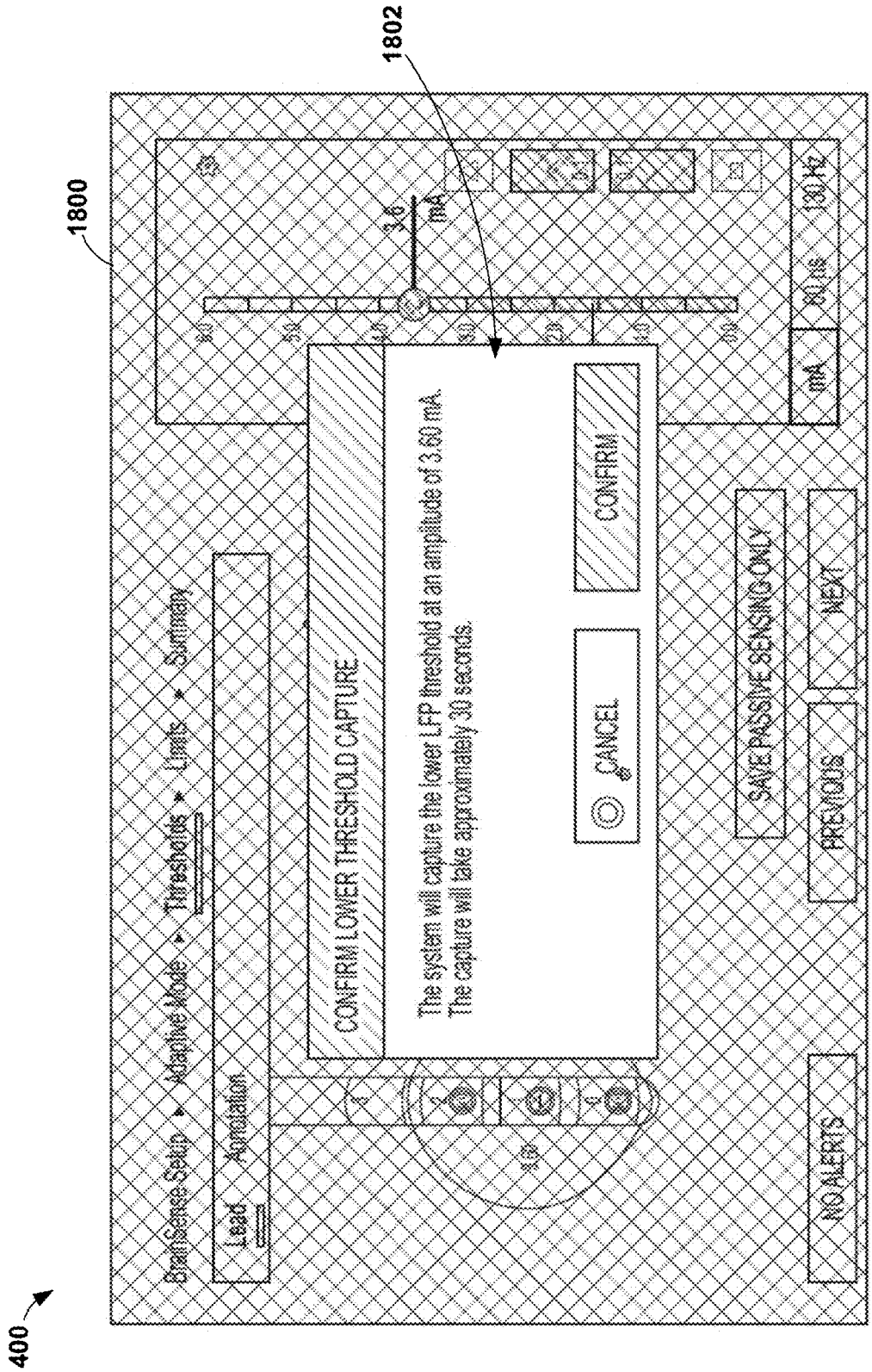

400
1800
1802
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
CONFIRM LOWER THRESHOLD CAPTURE
The system will capture the lower LFP threshold at an amplitude of 3.60 mA.
The capture will take approximately 30 seconds.
CANCEL
CONFIRM
SAVE PASSIVE SENSING ONLY
PREVIOUS
NEXT
NO ALERTS
3.6
mA
130 Hz
60 us
mA

FIG. 18

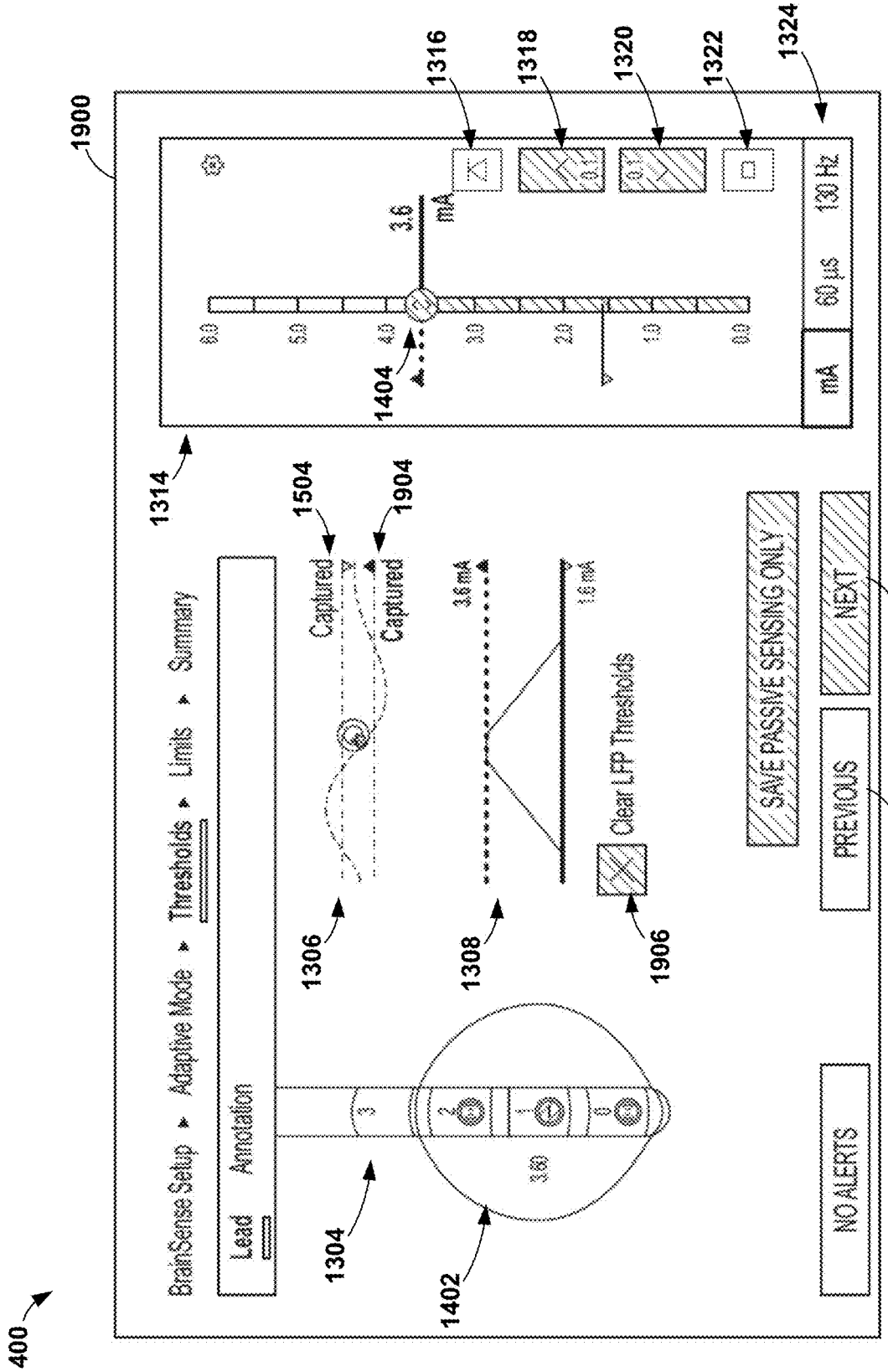

400
1900
1316
1318
1320
1322
1324
1314
1404
1504
1904
1306
1308
1906
1304
1402
1212
1210
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Lead
Annotation
Captured
Captured
3.6 mA
1.6 mA
Clear LFP Thresholds
SAVE PASSIVE SENSING ONLY
NEXT
PREVIOUS
NO ALERTS
3.6
mA
130 Hz
60 µs
mA

FIG. 19

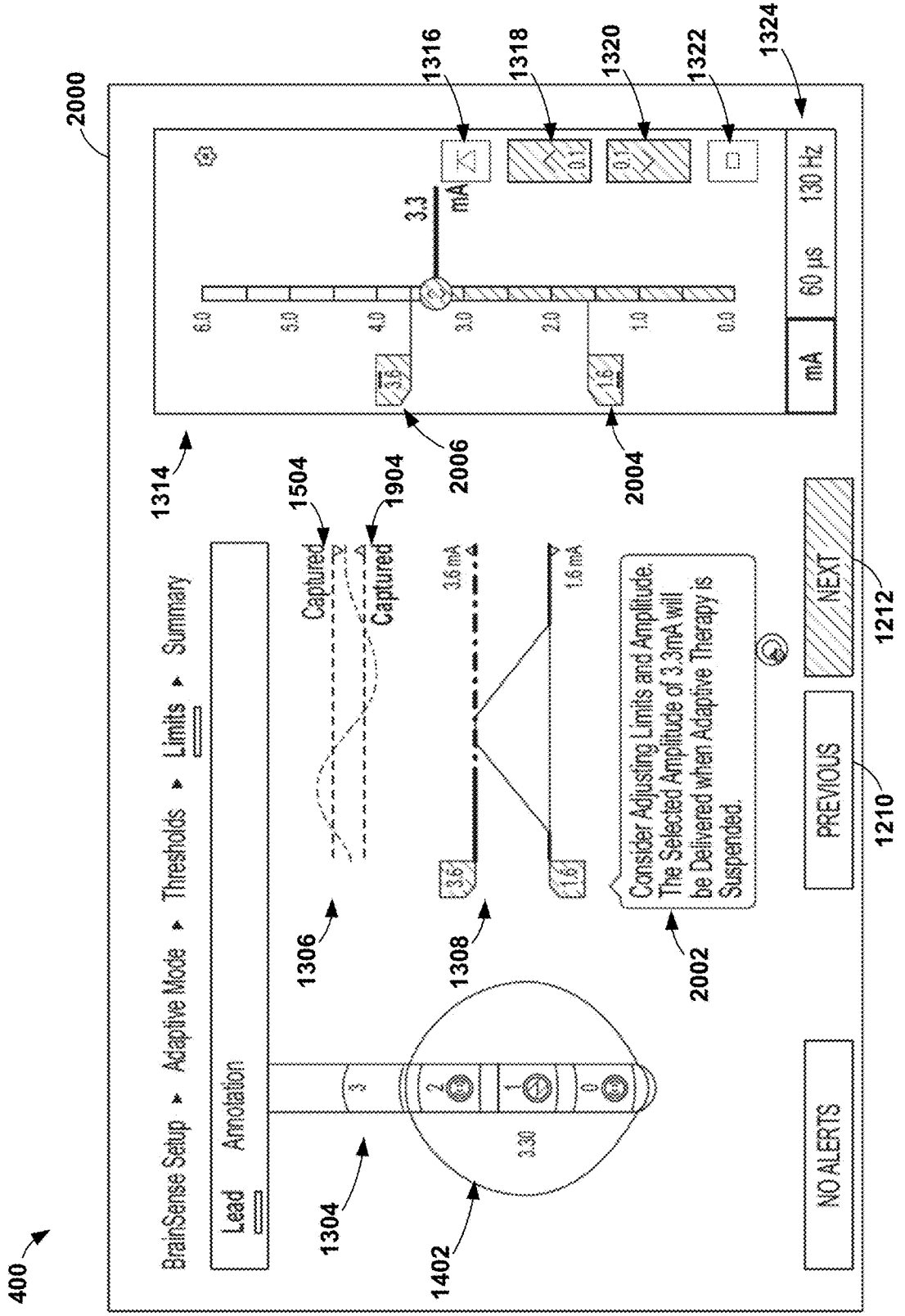

400
2000
1316
1318
1320
1322
1324
3.3
mA
130 Hz
60 µs
mA
6.0
5.0
4.0
3.0
2.0
1.0
0.0
3.6
1.6
1314
2006
2004
1504
1904
Captured
Captured
3.6 mA
1.6 mA
BrainSense Setup ▸ Adaptive Mode ▸ Thresholds ▸ Limits ▸ Summary
Lead Annotation
Consider Adjusting Limits and Amplitude. The Selected Amplitude of 3.3mA will be Delivered when Adaptive Therapy is Suspended.
NEXT
1212
PREVIOUS
1210
NO ALERTS
1306
1308
2002
1304
1402
3.3Ω

FIG. 20

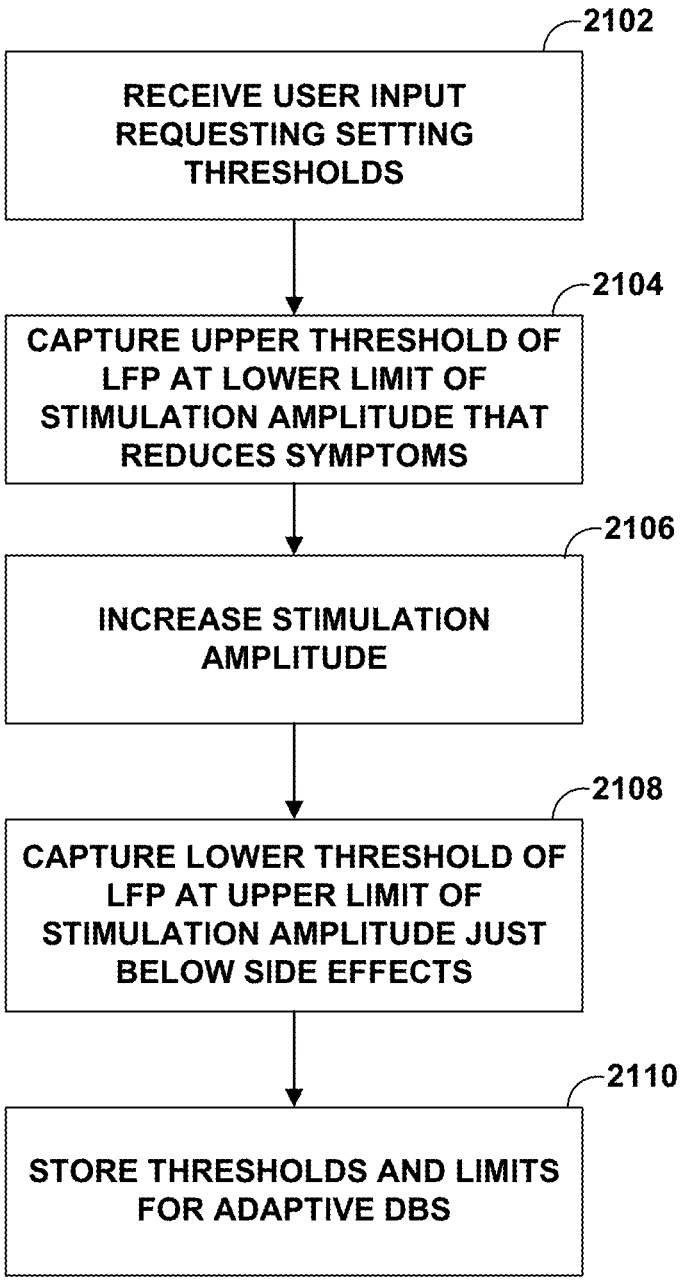

2102
RECEIVE USER INPUT REQUESTING SETTING THRESHOLDS
2104
CAPTURE UPPER THRESHOLD OF LFP AT LOWER LIMIT OF STIMULATION AMPLITUDE THAT REDUCES SYMPTOMS
2106
INCREASE STIMULATION AMPLITUDE
2108
CAPTURE LOWER THRESHOLD OF LFP AT UPPER LIMIT OF STIMULATION AMPLITUDE JUST BELOW SIDE EFFECTS
2110
STORE THRESHOLDS AND LIMITS FOR ADAPTIVE DBS

FIG. 21

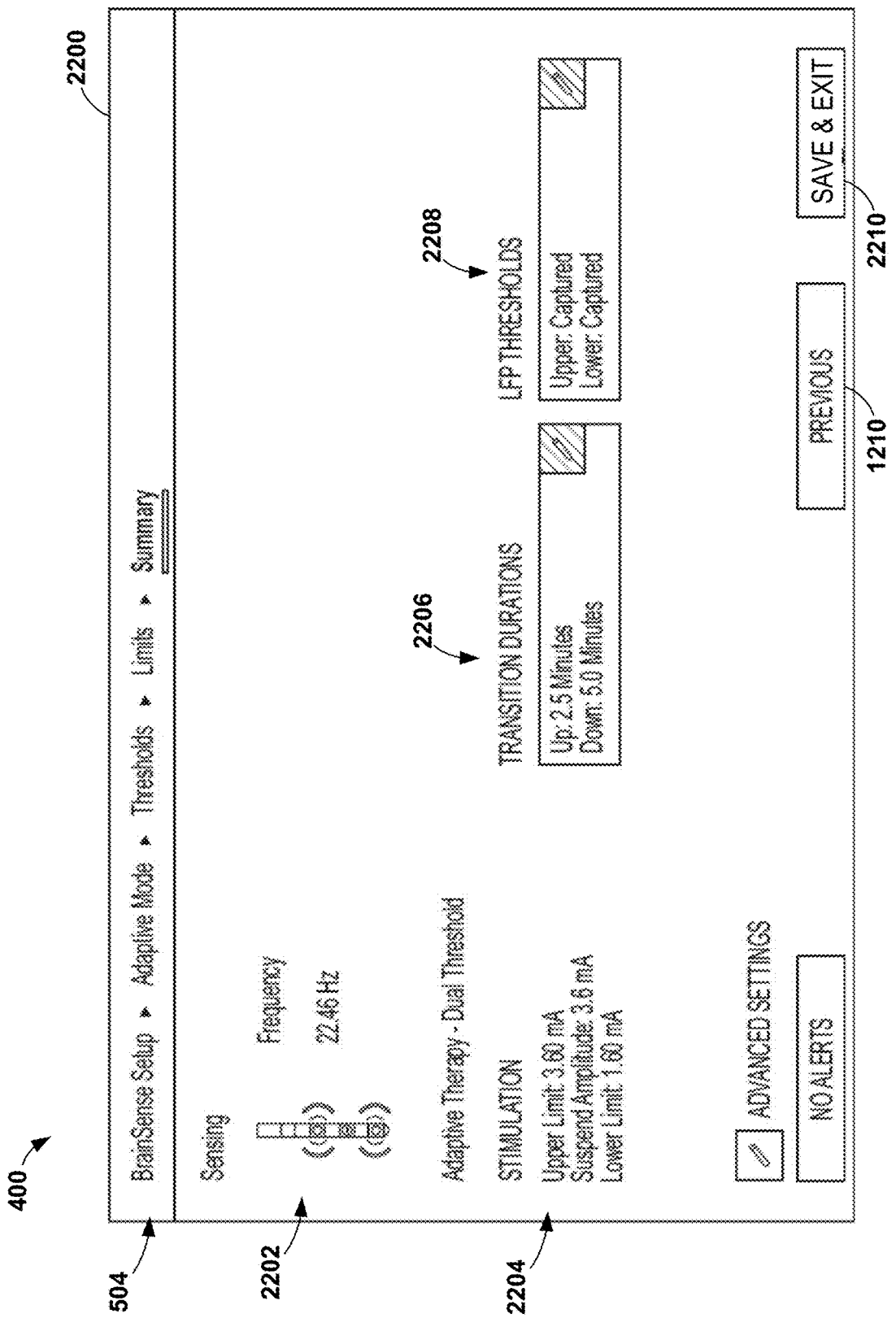

400
2200
BrainSense Setup
Adaptive Mode
Thresholds
Limits
Summary
Sensing
Frequency
22.46 Hz
Adaptive Therapy - Dual Threshold
STIMULATION
Upper Limit 3.60 mA
Suspend Amplitude 3.6 mA
Lower Limit 1.60 mA
ADVANCED SETTINGS
NO ALERTS
2206
TRANSITION DURATIONS
Up: 2.5 Minutes
Down: 5.0 Minutes
2208
LFP THRESHOLDS
Upper: Captured
Lower: Captured
PREVIOUS
SAVE & EXIT
1210
2210
504
2202
2204

FIG. 22

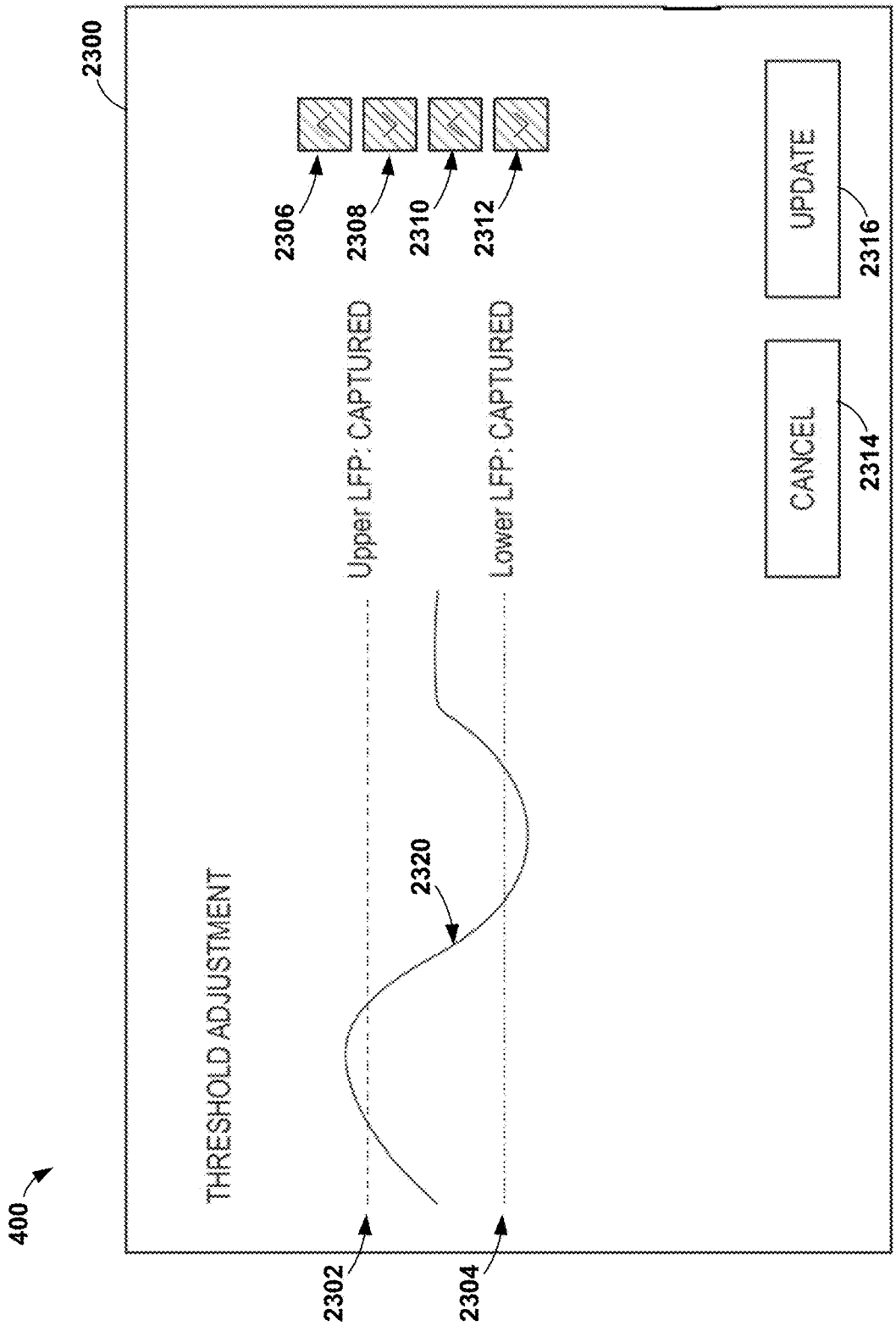

400
2300
THRESHOLD ADJUSTMENT
2306
2308
2310
2312
Upper LFP; CAPTURED
Lower LFP; CAPTURED
2320
UPDATE
2316
CANCEL
2314
2302
2304

FIG. 23

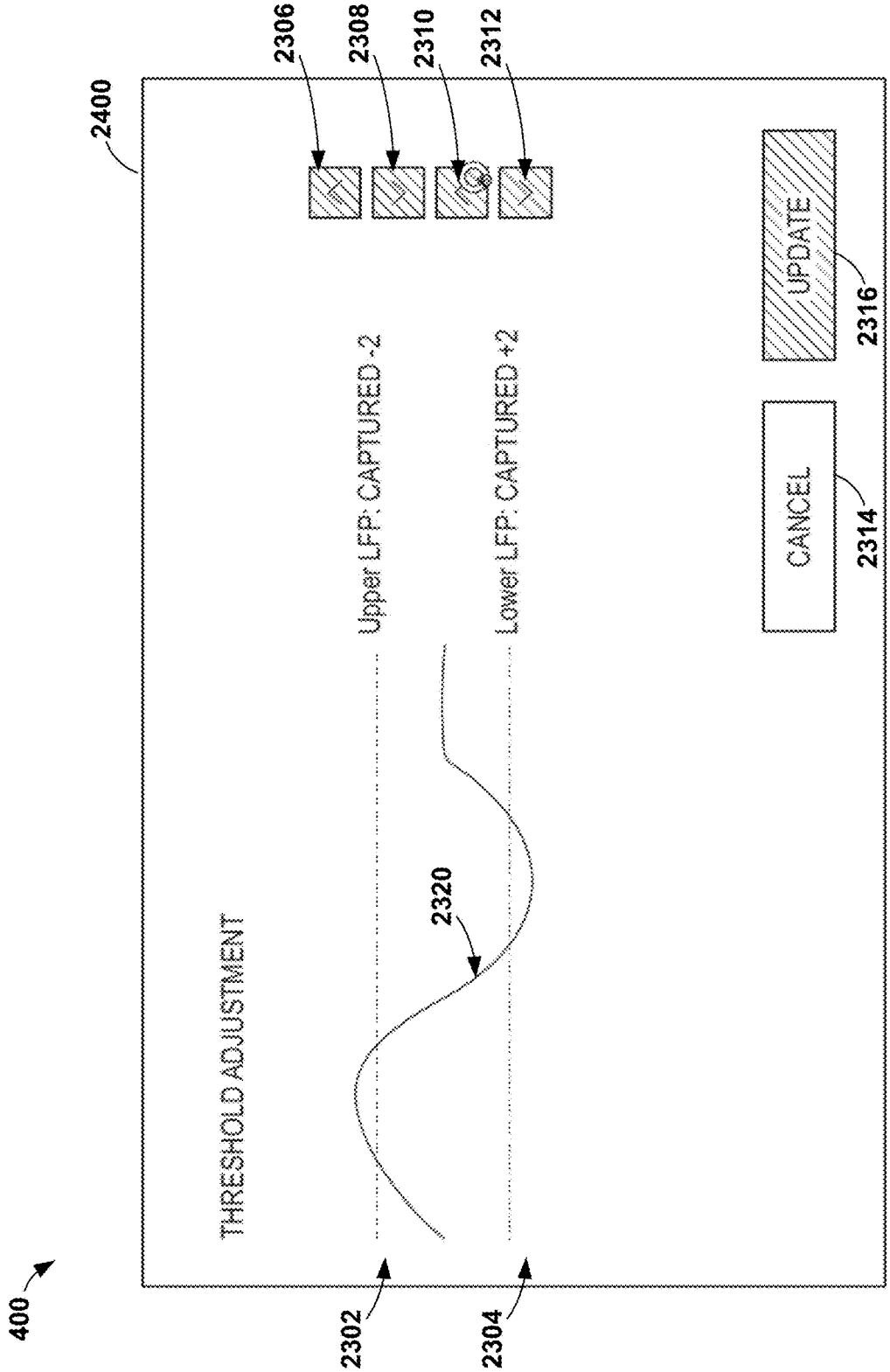

400
2400
2306
2308
2310
2312
UPDATE
2316
CANCEL
2314
Upper LFP: CAPTURED -2
Lower LFP: CAPTURED +2
2320
THRESHOLD ADJUSTMENT
2302
2304

FIG. 24

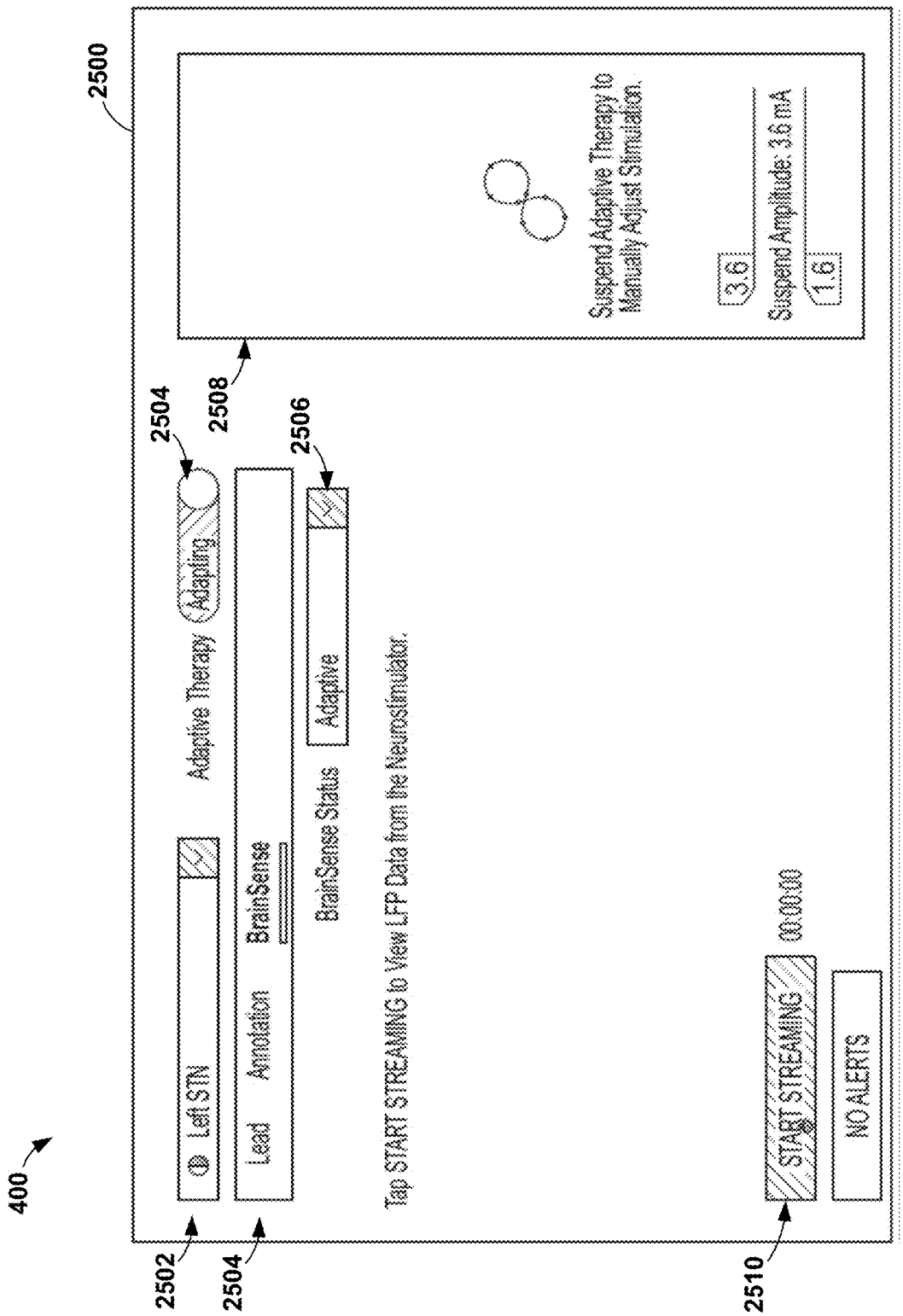

400
2500
Left STN
Lead
Annotation
BrainSense
BrainSense Status
Adaptive
Adaptive Therapy
Adapting
Tap START STREAMING to View LFP Data from the Neurostimulator.
START STREAMING
00:00:00
NO ALERTS
Suspend Adaptive Therapy to Manually Adjust Stimulation.
3.6
Suspend Amplitude: 3.6 mA
1.6
2502
2504
2504
2506
2508
2510

FIG. 25

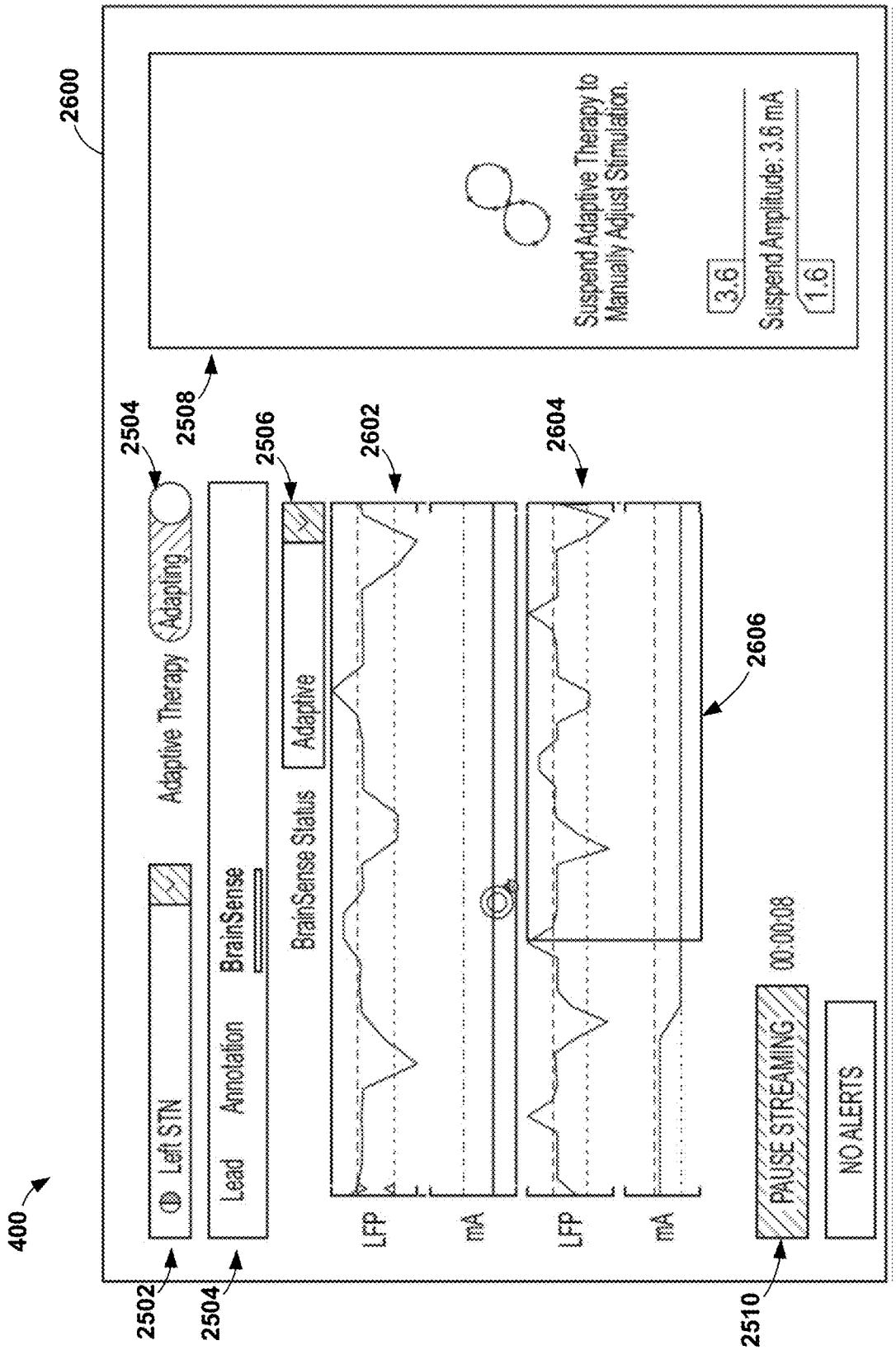

400
2600
2502
2504
2504
2506
2508
2602
2604
2606
2510
Left STN
Lead
Annotation
BrainSense
Adaptive Therapy
Adapting
BrainSense Status
Adaptive
LFP
mA
LFP
mA
PAUSE STREAMING
00:00:08
NO ALERTS
Suspend Adaptive Therapy to Manually Adjust Simulation.
3.6
Suspend Amplitude: 3.6 mA
1.6

FIG. 26

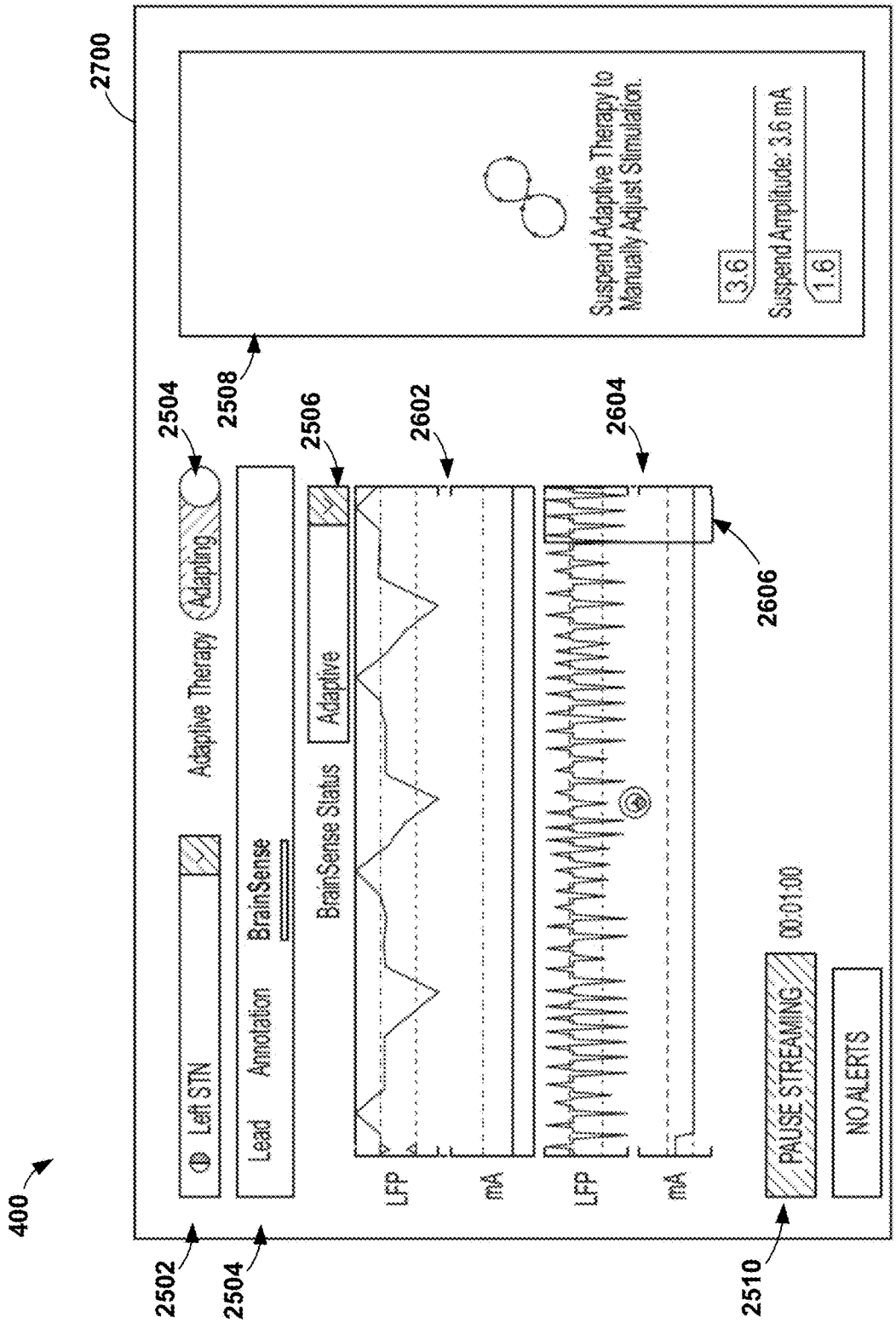

400
2700
2502
2504
2508
2506
2602
2604
2606
2510
Left STN
Lead
Annotation
BrainSense
Adaptive Therapy
Adapting
BrainSense Status
Adaptive
LFP
mA
LFP
mA
PAUSE STREAMING
00:01:00
NO ALERTS
Suspend Adaptive Therapy to Manually Adjust Stimulation.
3.6
Suspend Amplitude: 3.6 mA
1.6

FIG. 27

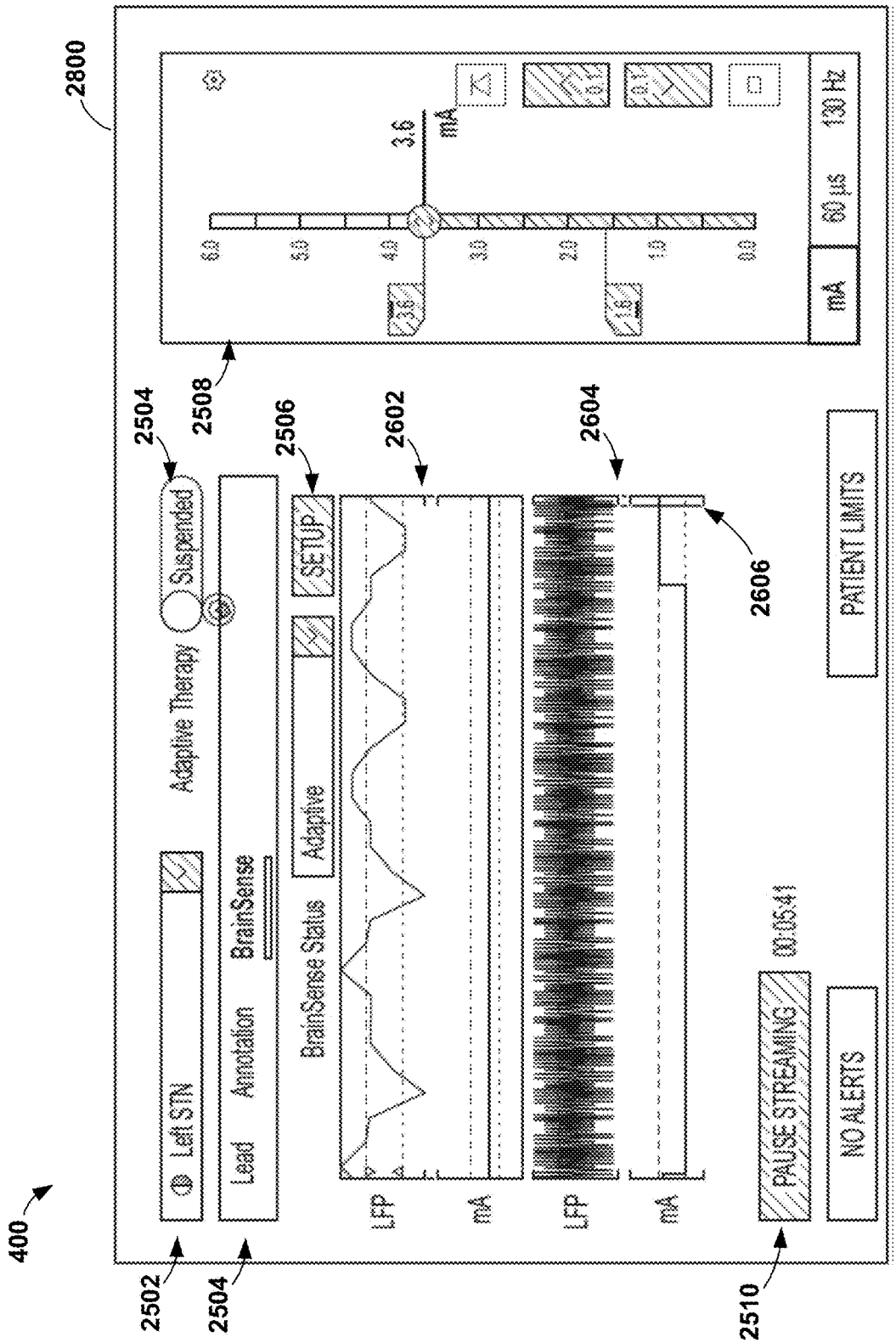

400
2800
2502
2504
2504
2506
2508
2602
2604
2606
2510
Left STN
Lead
Annotation
BrainSense
Adaptive Therapy
Suspended
BrainSense Status
Adaptive
SETUP
LFP
mA
LFP
mA
3.6
mA
6.0
5.0
4.0
3.0
2.0
1.0
0.0
3.6
3.6
mA
60 µs
130 Hz
PATIENT LIMITS
PAUSE STREAMING
00:05:41
NO ALERTS

FIG. 28

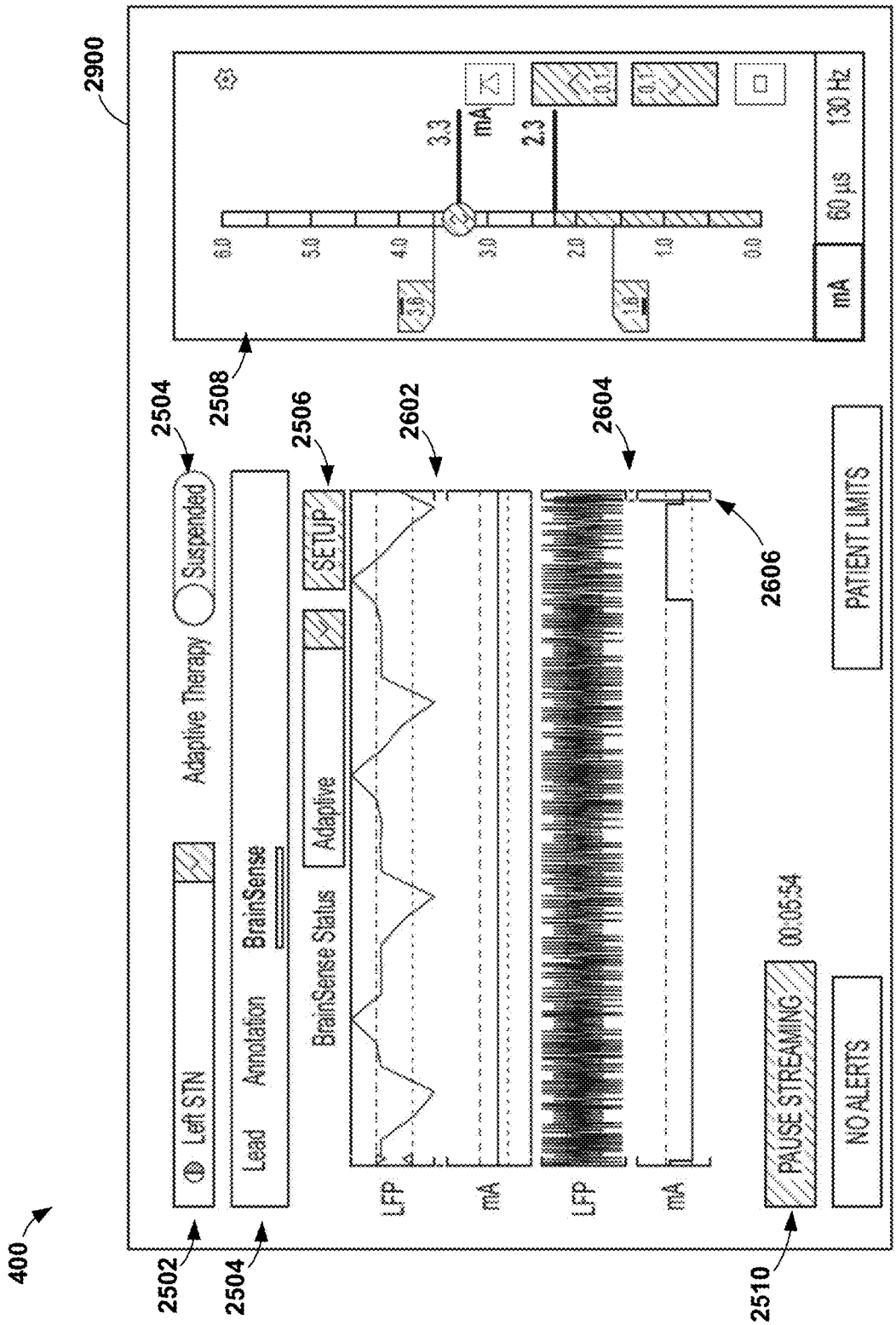

400
2900
2502
2504
2504
2506
2508
2602
2604
2606
2510
Left STN
Lead
Annotation
BrainSense
Adaptive Therapy
Suspended
BrainSense Status
Adaptive
SETUP
LFP
mA
LFP
mA
3.3
mA
2.3
6.0
5.0
4.0
3.0
2.0
1.0
0.0
130 Hz
60 µs
mA
PATIENT LIMITS
PAUSE STREAMING
00:05:54
NO ALERTS

FIG. 29

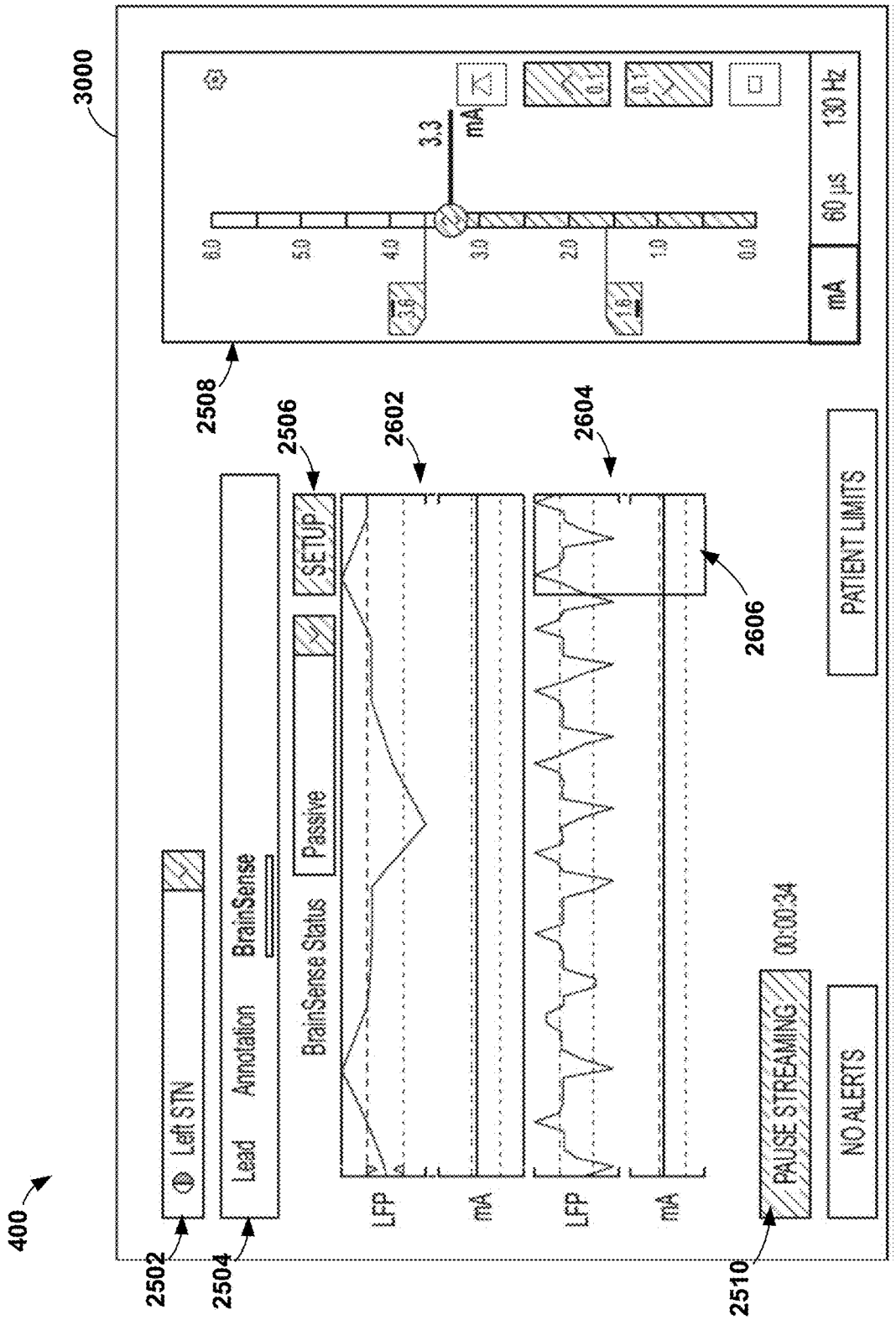

400
3000
2502
2504
2506
2508
2510
2602
2604
2606
Left STN
Lead
Annotation
BrainSense
BrainSense Status
Passive
SETUP
LFP
mA
LFP
mA
PAUSE STREAMING
00:00:34
NO ALERTS
PATIENT LIMITS
3.3
mA
130 Hz
60 µs
mA
8.0
5.0
4.0
3.0
2.0
1.0
0.0

FIG. 30

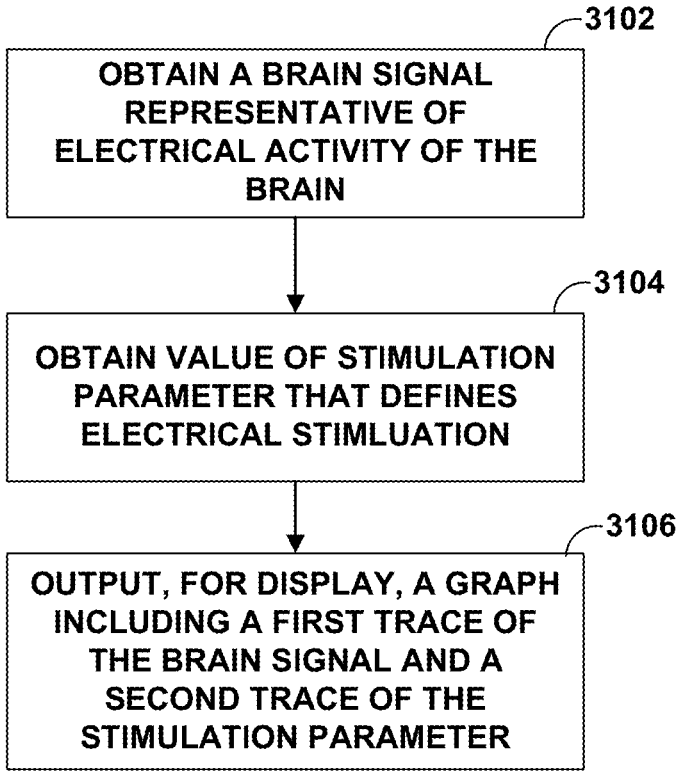

3102
OBTAIN A BRAIN SIGNAL REPRESENTATIVE OF ELECTRICAL ACTIVITY OF THE BRAIN
3104
OBTAIN VALUE OF STIMULATION PARAMETER THAT DEFINES ELECTRICAL STIMLUATION
3106
OUTPUT, FOR DISPLAY, A GRAPH INCLUDING A FIRST TRACE OF THE BRAIN SIGNAL AND A SECOND TRACE OF THE STIMULATION PARAMETER

FIG. 31

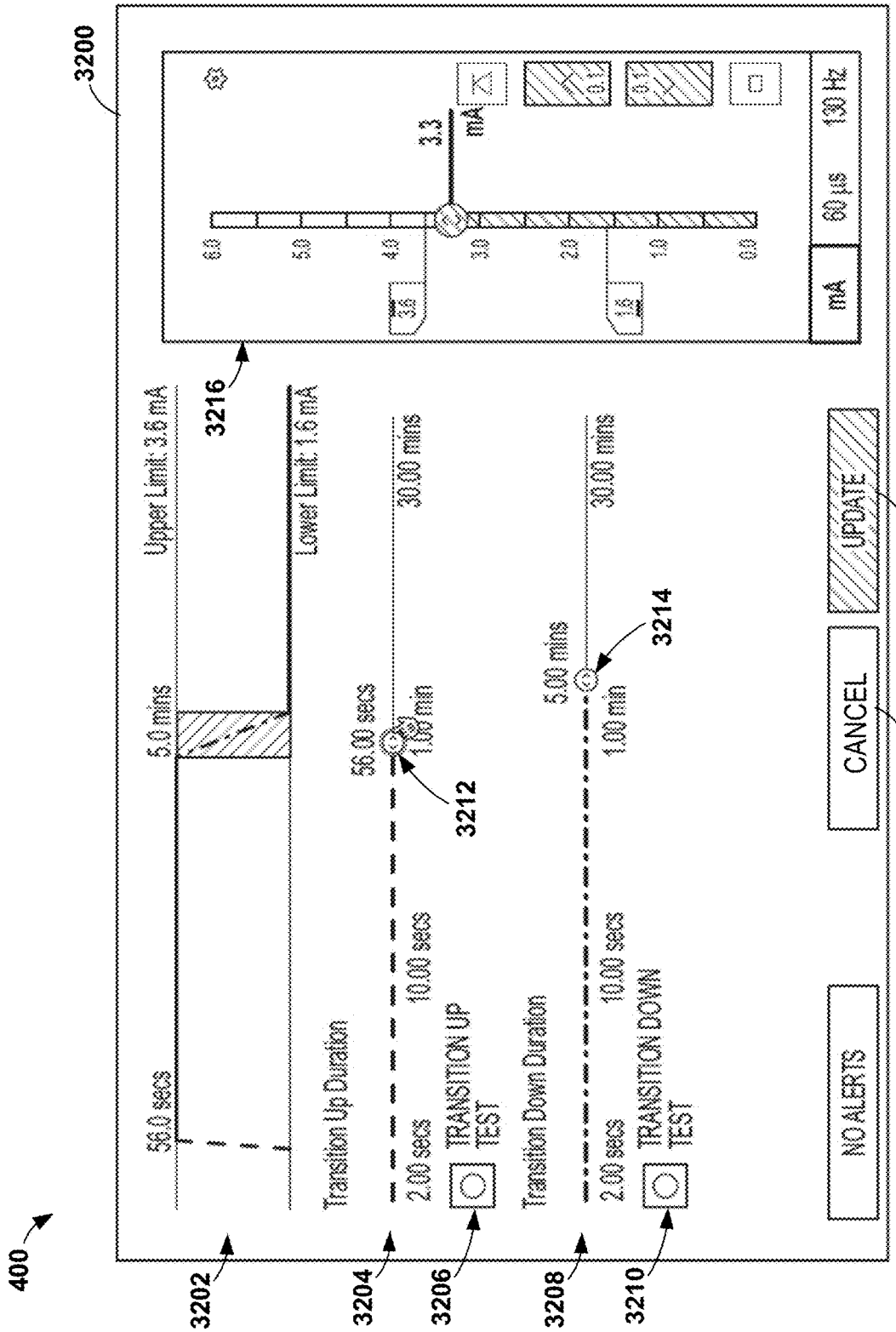

400
3200
3202
3204
3206
3208
3210
3212
3214
3216
3220
3222
Upper Limit: 3.6 mA
Lower Limit: 1.6 mA
5.0 mins
56.0 secs
Transition Up Duration
2.00 secs
10.00 secs
TRANSITION UP TEST
Transition Down Duration
TRANSITION DOWN TEST
56.00 secs
30.00 mins
1.00 min
5.00 mins
NO ALERTS
CANCEL
UPDATE
3.3
mA
130 Hz
60 µs
6.0
5.0
4.0
3.0
2.0
1.0
0.0

FIG. 32

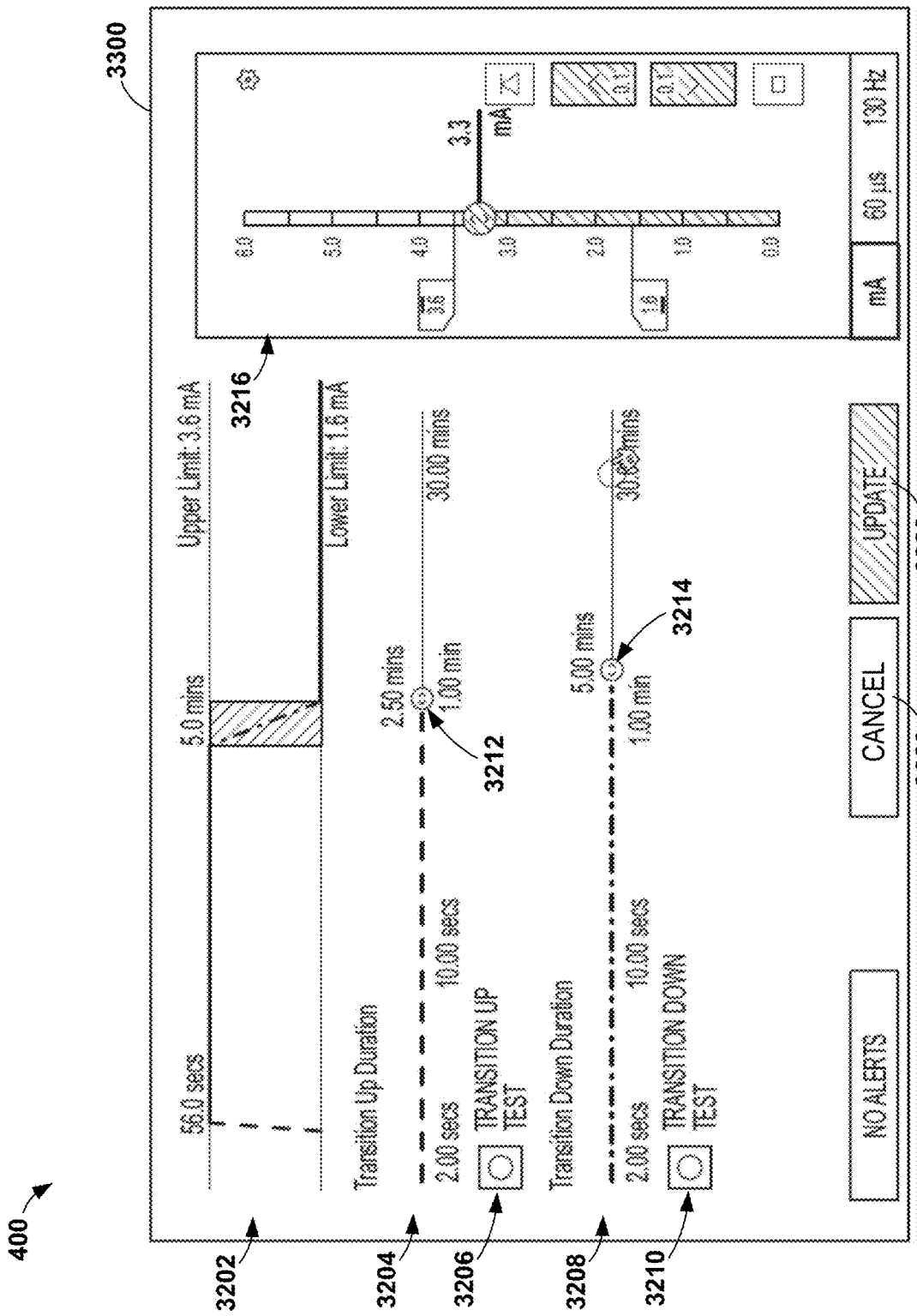

400
3300
3216
3.3
mA
6.0
5.0
4.0
3.6
3.0
2.0
1.6
1.0
0.0
mA
60 µs
130 Hz
Upper Limit 3.6 mA
Lower Limit 1.6 mA
5.0 mins
56.0 secs
Transition Up Duration
2.50 mins
30.00 mins
1.00 min
10.00 secs
2.00 secs
TRANSITION UP TEST
3212
Transition Down Duration
5.00 mins
30.00 mins
1.00 min
10.00 secs
2.00 secs
TRANSITION DOWN TEST
3214
NO ALERTS
CANCEL
UPDATE
3220
3222
3202
3204
3206
3208
3210

FIG. 33

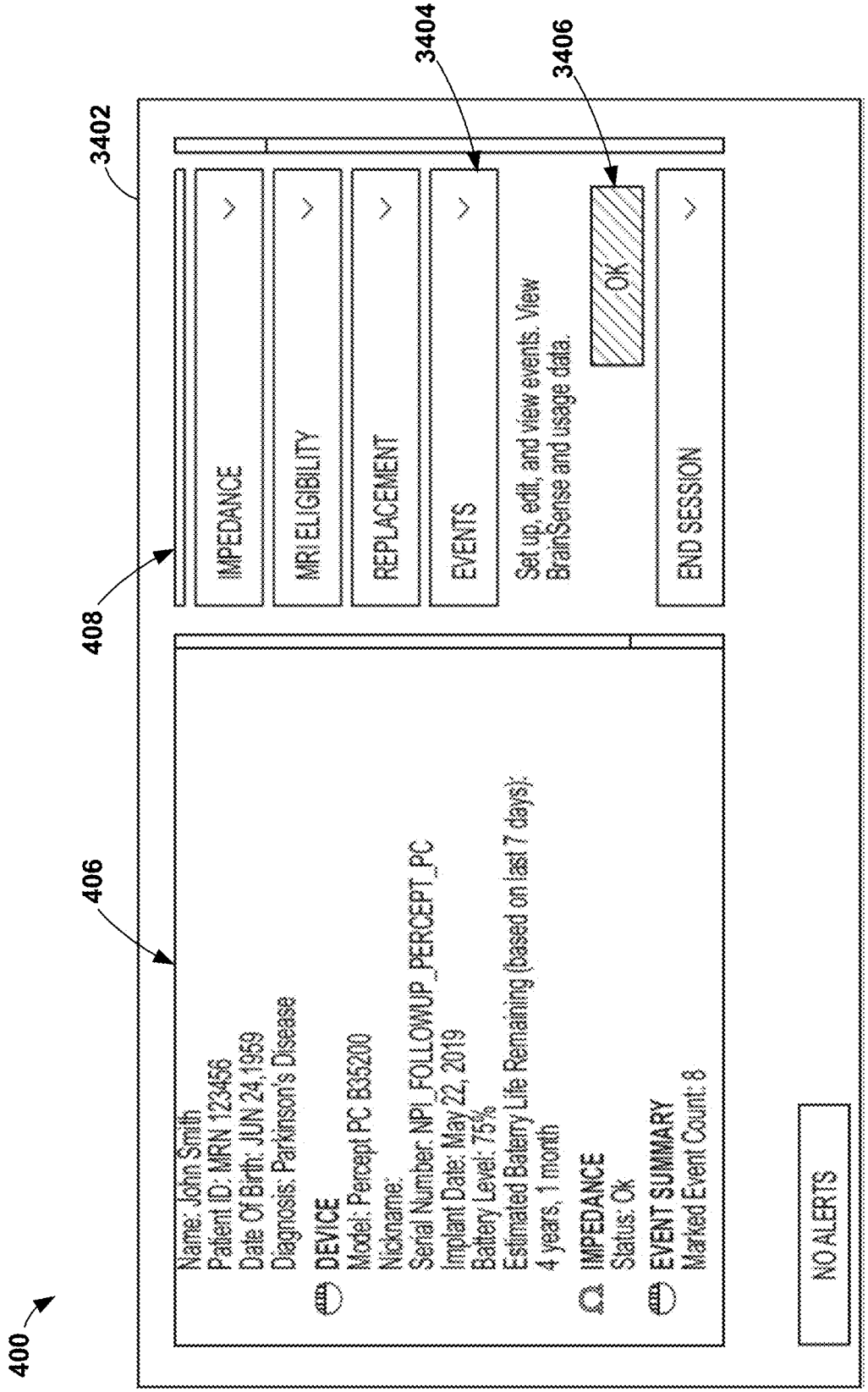

400
3402
3404
3406
408
406
IMPEDANCE
MRI ELIGIBILITY
REPLACEMENT
EVENTS
Set up, edit, and view events. View BrainSense and usage data.
OK
END SESSION
Name: John Smith
Patient ID: MRN 123456
Date Of Birth: JUN 24,1959
Diagnosis: Parkinson's Disease
DEVICE
Model: Percept PC B35200
Nickname:
Serial Number: NPI_FOLLOWUP_PERCEPT_PC
Implant Date: May 22, 2019
Battery Level: 75%
Estimated Battery Life Remaining (based on last 7 days):
4 years, 1 month
IMPEDANCE
Status: Ok
EVENT SUMMARY
Marked Event Count: 8
NO ALERTS

FIG. 34

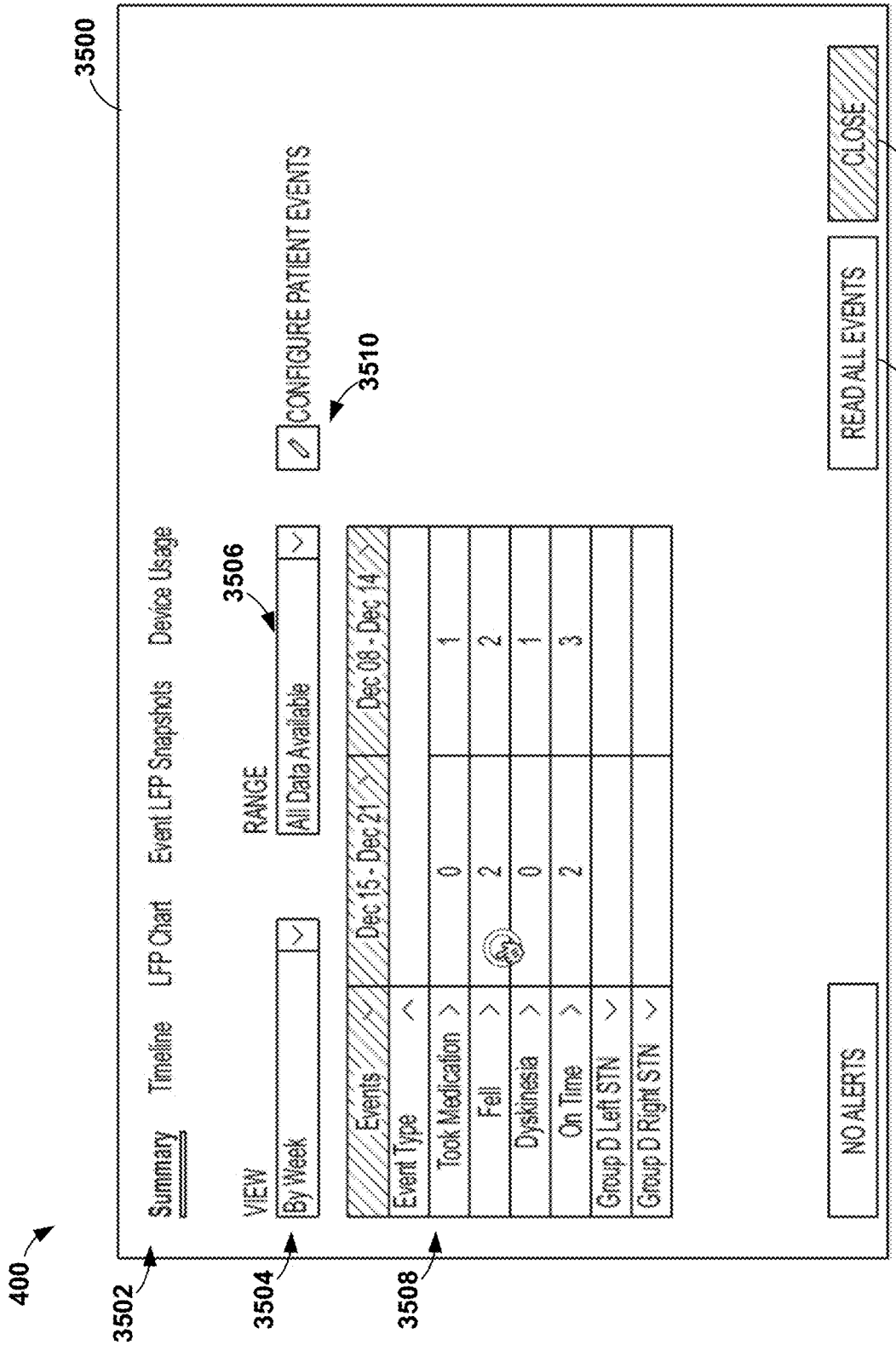

400
3500
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
VIEW
By Week
RANGE
All Data Available
CONFIGURE PATIENT EVENTS
3502
3504
3506
3508
3510
Events
Dec 15 - Dec 21
Dec 08 - Dec 14
Event Type
Took Medication
Fall
Dyskinesia
On Time
Group D Left STN
Group D Right STN
0
2
0
2
1
2
1
3
NO ALERTS
READ ALL EVENTS
CLOSE
3512
3514

FIG. 35

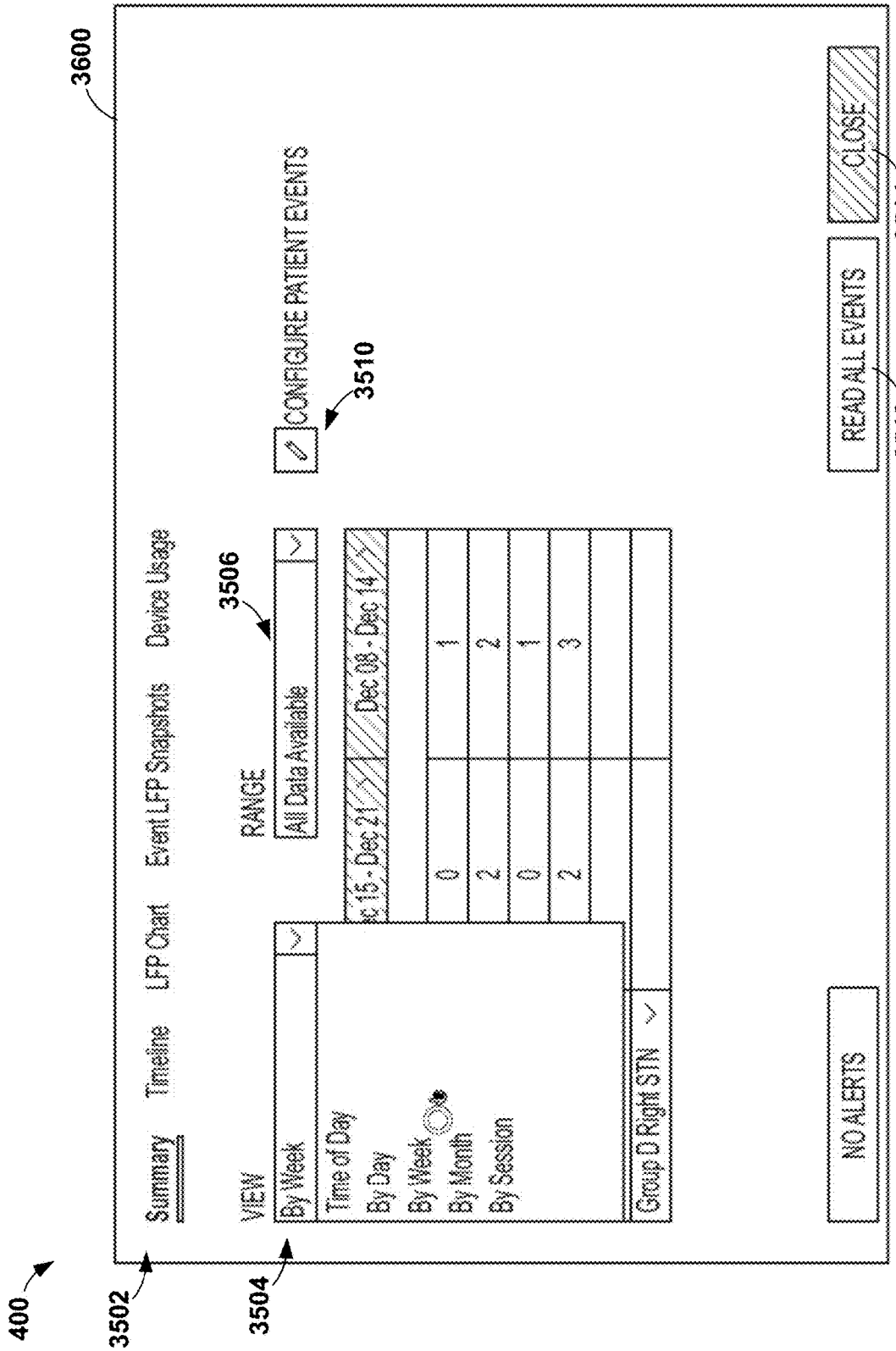

400
3502
3504
3600
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
VIEW
By Week
Time of Day
By Day
By Week
By Month
By Session
RANGE
All Data Available
3506
CONFIGURE PATIENT EVENTS
3510
Dec 15 - Dec 21
Dec 08 - Dec 14
0
2
0
2
1
2
1
3
Group D Right STN
NO ALERTS
READ ALL EVENTS
3512
CLOSE
3514

FIG. 36

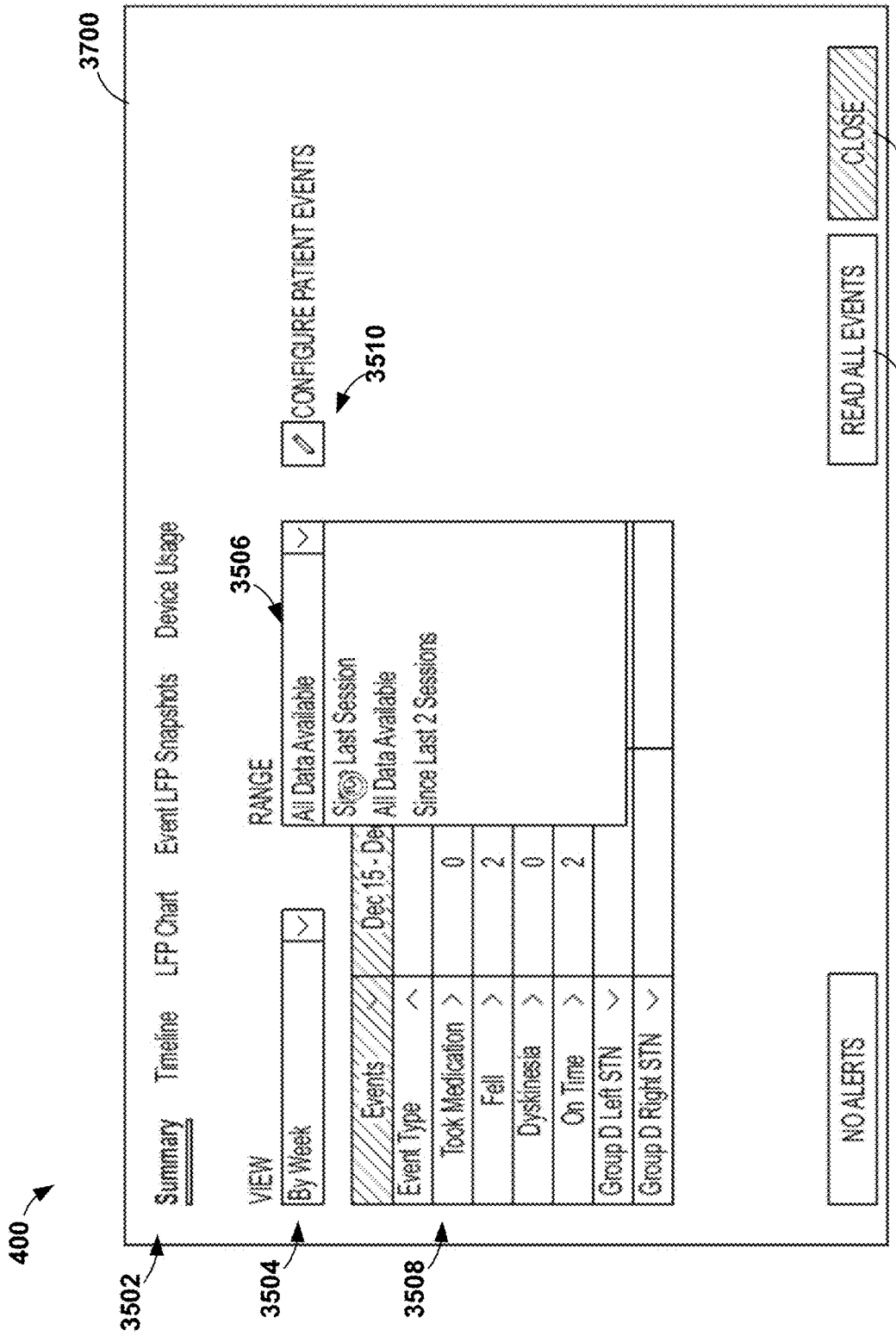

400
3700
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
VIEW
By Week
RANGE
All Data Available
Show Last Session
All Data Available
Since Last 2 Sessions
CONFIGURE PATIENT EVENTS
3510
3506
Events
Dec 15 - De
Event Type
Took Medication
Fall
Dyskinesia
On Time
Group D Left STN
Group D Right STN
0
2
0
2
NO ALERTS
READ ALL EVENTS
CLOSE
3514
3512
3502
3504
3508

FIG. 37

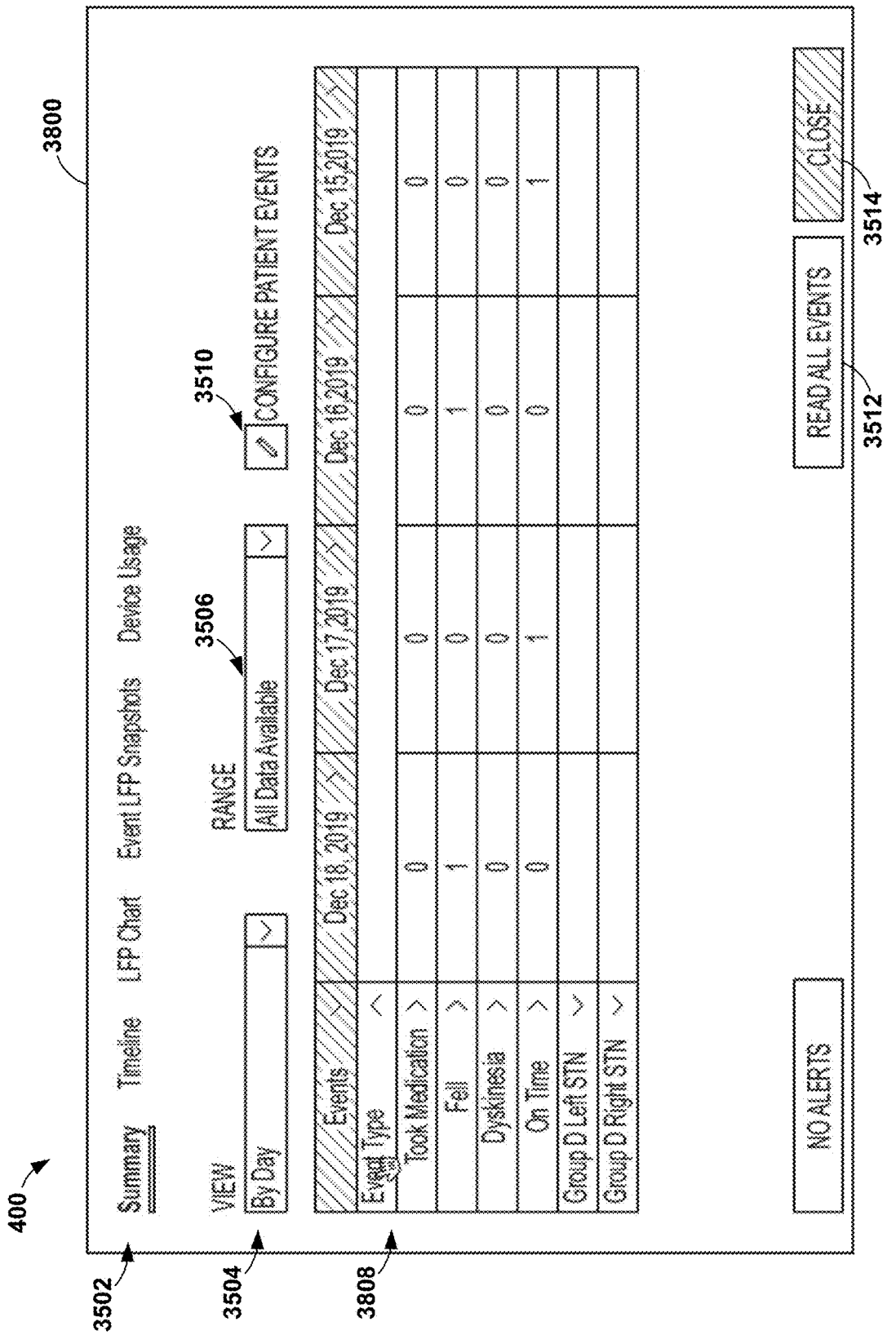

400
3800
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
VIEW
By Day
RANGE
All Data Available
3506
3510
CONFIGURE PATIENT EVENTS
Events
Dec 18, 2019
Dec 17, 2019
Dec 16, 2019
Dec 15, 2019
Event Type
Took Medication
Fell
Dyskinesia
On Time
Group D Left STN
Group D Right STN
NO ALERTS
READ ALL EVENTS
CLOSE
3502
3504
3808
3512
3514

FIG. 38

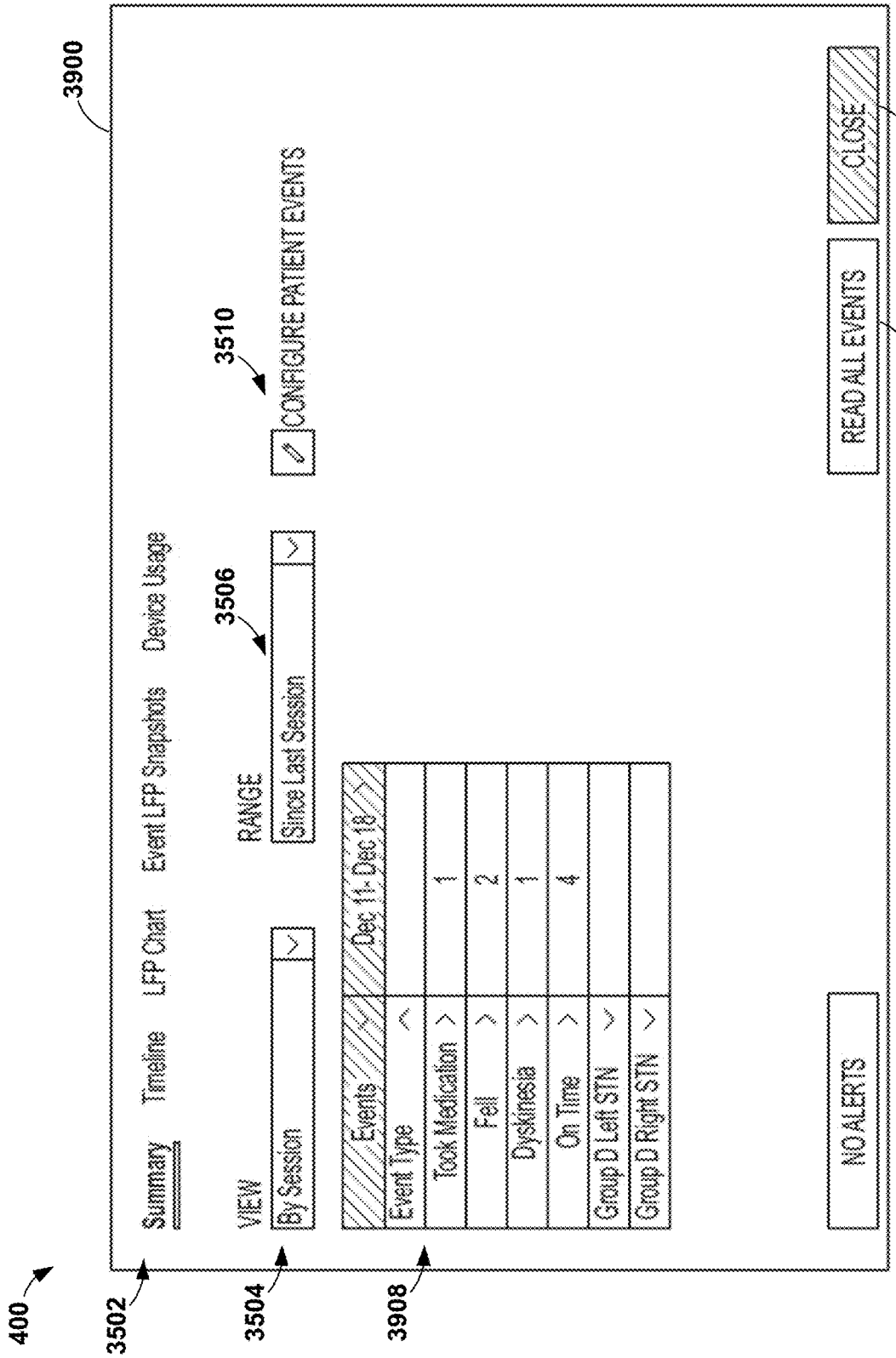

400
3502
3504
3908
3900
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
VIEW
By Session
RANGE
Since Last Session
3506
3510
CONFIGURE PATIENT EVENTS
Events
Dec 11- Dec 18
Event Type
Took Medication
Fell
Dyskinesia
On Time
Group D Left STN
Group D Right STN
1
2
1
4
NO ALERTS
READ ALL EVENTS
3512
CLOSE
3514

FIG. 39

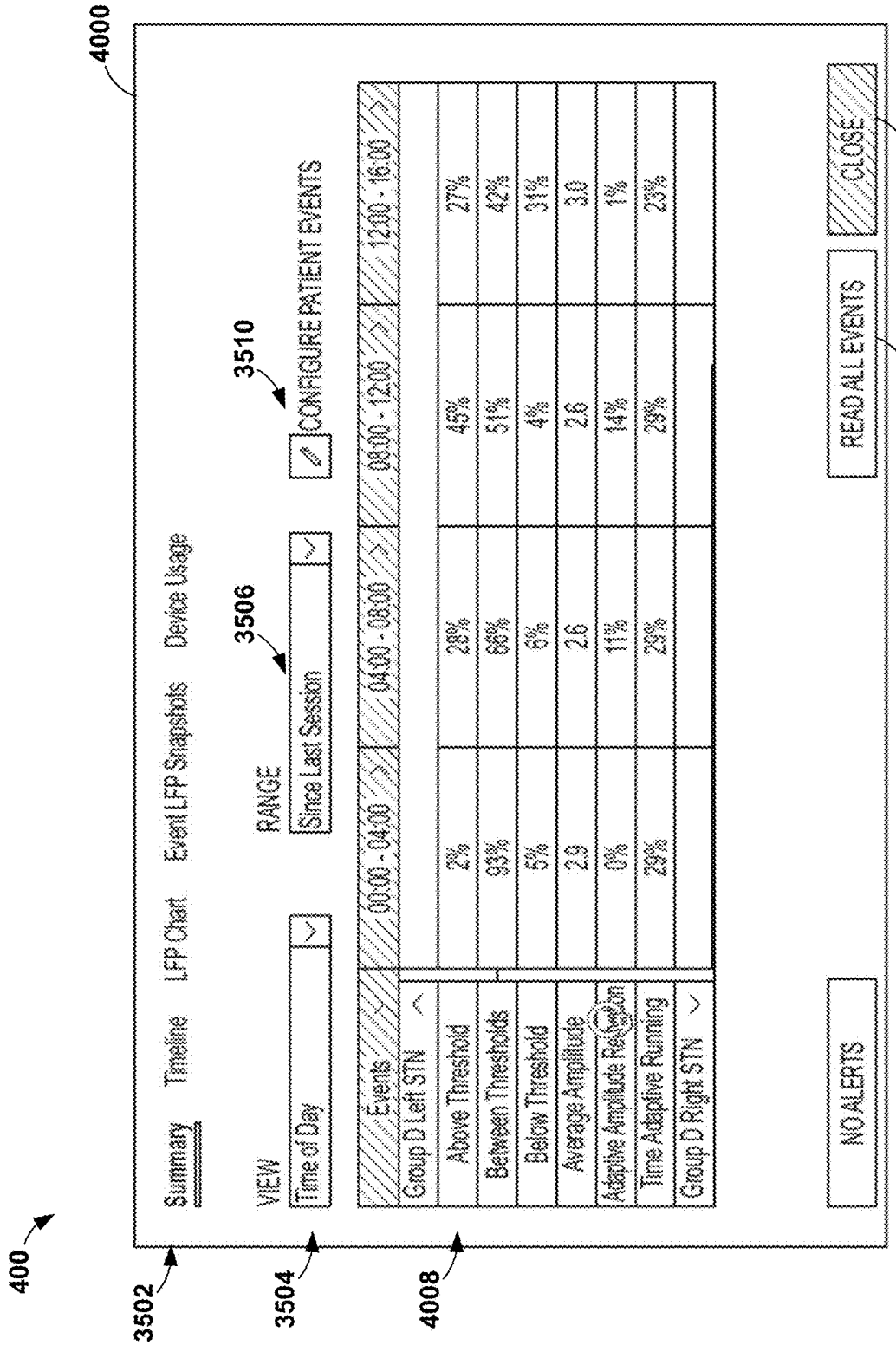

400
4000
3502
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
3504
VIEW
Time of Day
RANGE
3506
Since Last Session
3510
CONFIGURE PATIENT EVENTS
4008
Events
00:00 - 04:00
04:00 - 08:00
08:00 - 12:00
12:00 - 16:00
Group D Left STN
Above Threshold
2%
28%
45%
27%
Between Thresholds
93%
66%
51%
42%
Below Threshold
5%
6%
4%
31%
Average Amplitude
2.9
2.6
2.6
3.0
Adaptive Amplitude Range
0%
11%
14%
1%
Time Adaptive Running
29%
29%
29%
23%
Group D Right STN
NO ALERTS
READ ALL EVENTS
3512
CLOSE
3514

FIG. 40

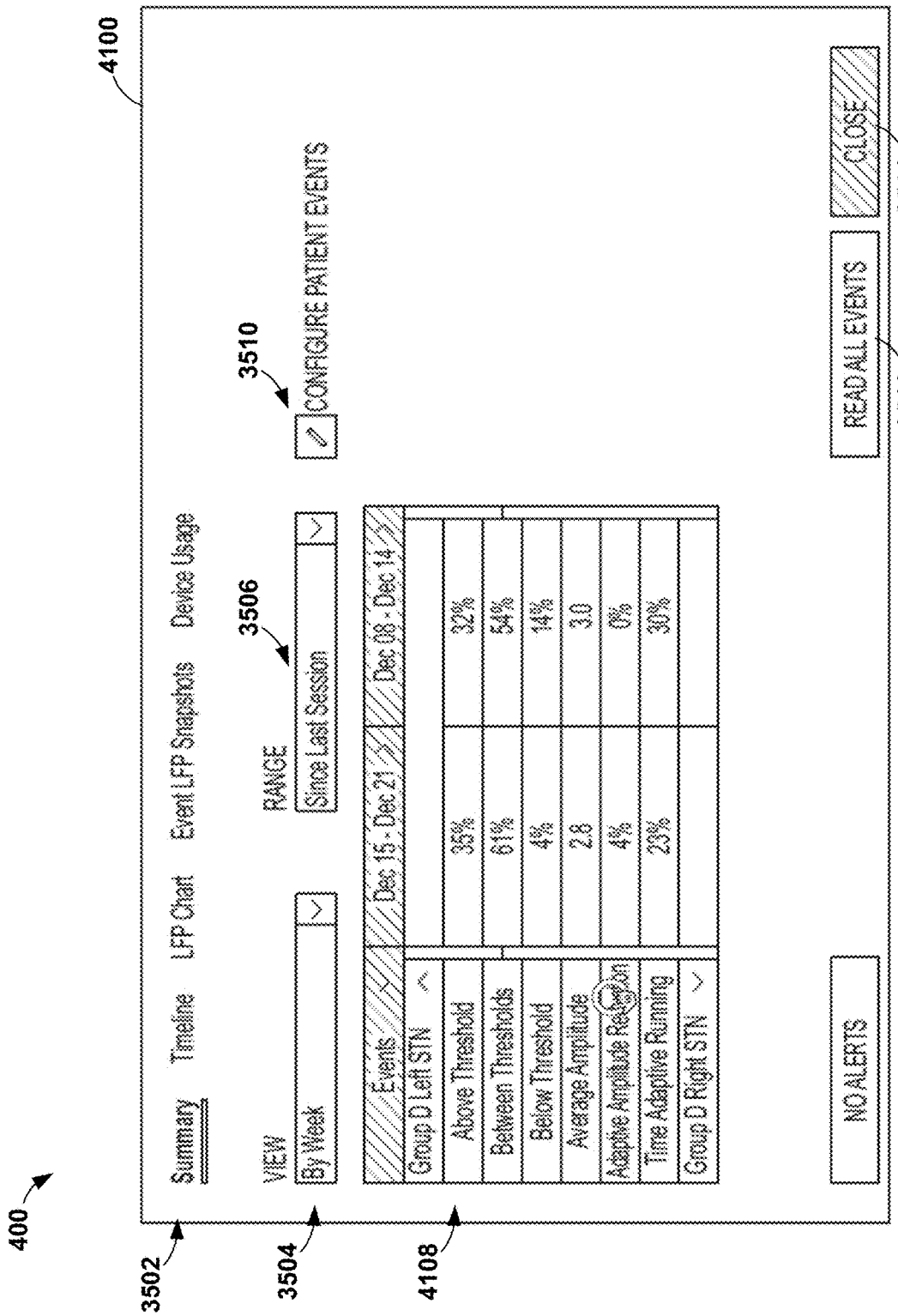

400
4100
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
VIEW
By Week
RANGE
Since Last Session
3506
3510
CONFIGURE PATIENT EVENTS
Events
Dec 15 - Dec 21
Dec 08 - Dec 14
Group D Left STN
Above Threshold
35%
32%
Between Thresholds
61%
54%
Below Threshold
4%
14%
Average Amplitude
2.8
3.0
Adaptive Amplitude Region
4%
0%
Time Adaptive Running
23%
30%
Group D Right STN
NO ALERTS
READ ALL EVENTS
CLOSE
3512
3514
3502
3504
4108

FIG. 41

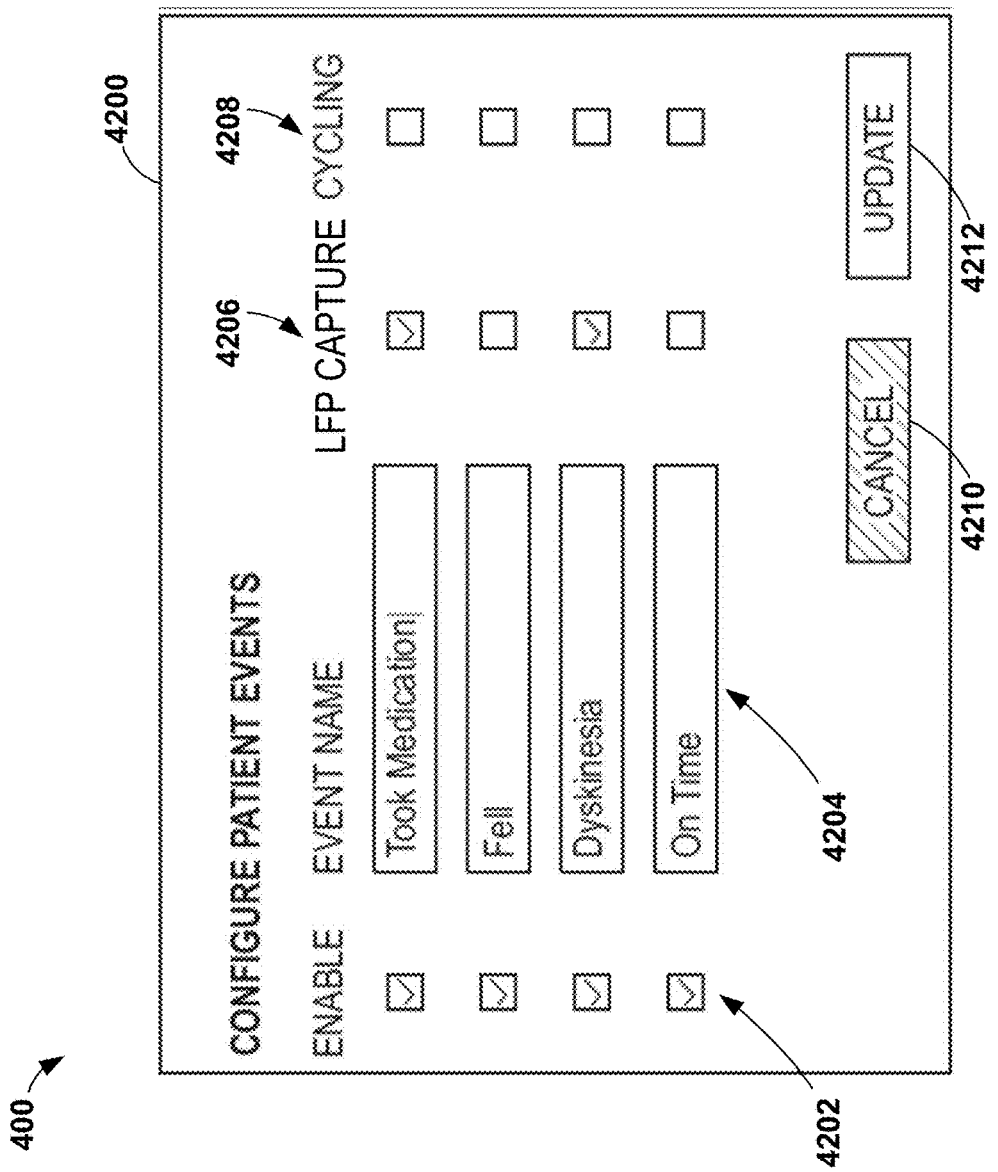

400
4200
CONFIGURE PATIENT EVENTS
ENABLE
EVENT NAME
4206
LFP CAPTURE
4208
CYCLING
Took Medication
Fell
Dyskinesia
On Time
4202
4204
CANCEL
UPDATE
4210
4212

FIG. 42

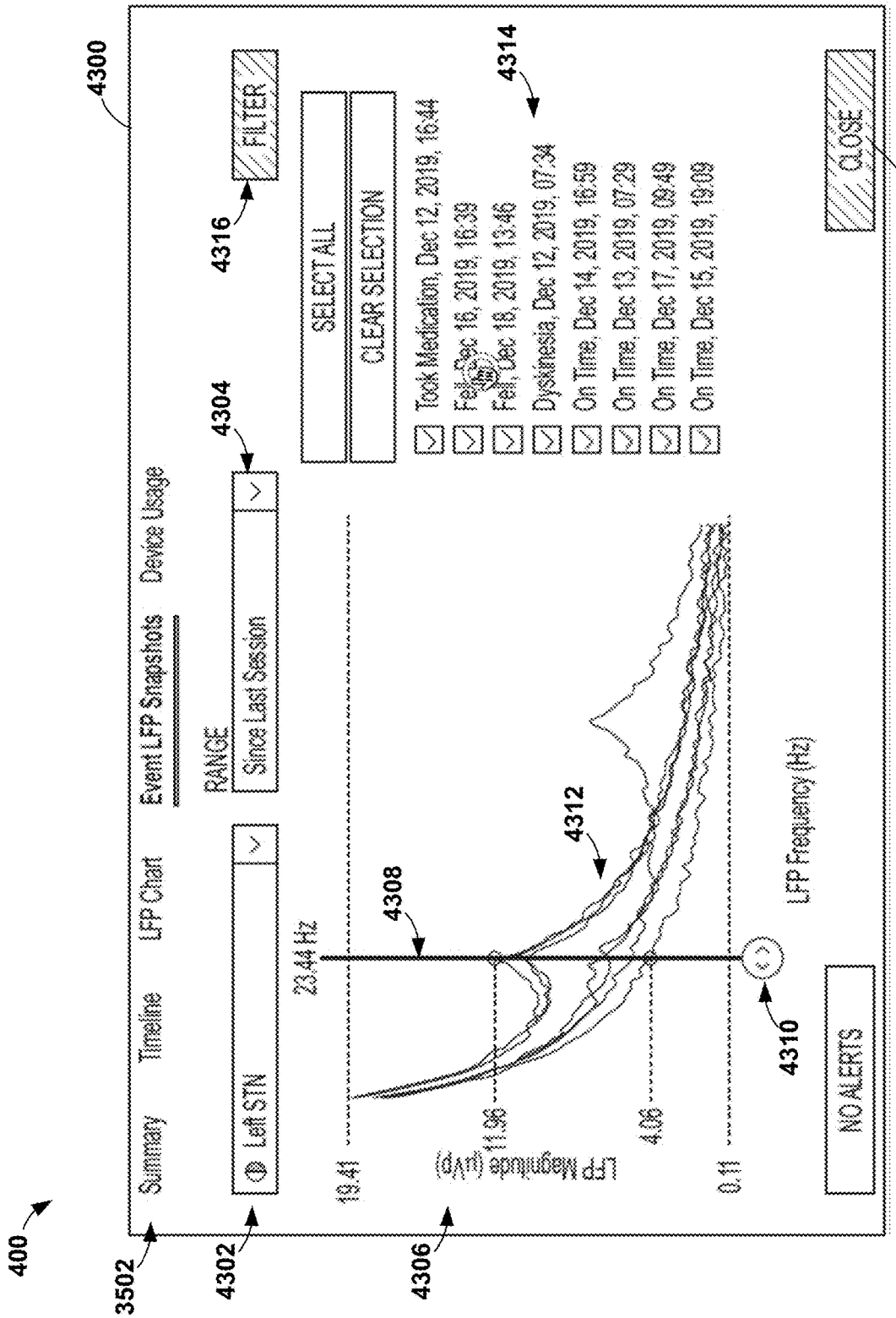

400
4300
3502
4302
4306
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
RANGE
Since Last Session
4304
4316
FILTER
SELECT ALL
CLEAR SELECTION
4314
Took Medication, Dec 12, 2019, 16:44
Felt Dec 16, 2019, 16:39
Felt Dec 18, 2019, 13:46
Dyskinesia, Dec 12, 2019, 07:34
On Time, Dec 14, 2019, 16:59
On Time, Dec 13, 2019, 07:29
On Time, Dec 17, 2019, 09:49
On Time, Dec 15, 2019, 19:09
4312
4308
23.44 Hz
19.41
11.96
4.06
0.11
LFP Magnitude (uVp)
LFP Frequency (Hz)
4310
NO ALERTS
CLOSE
4318

FIG. 43

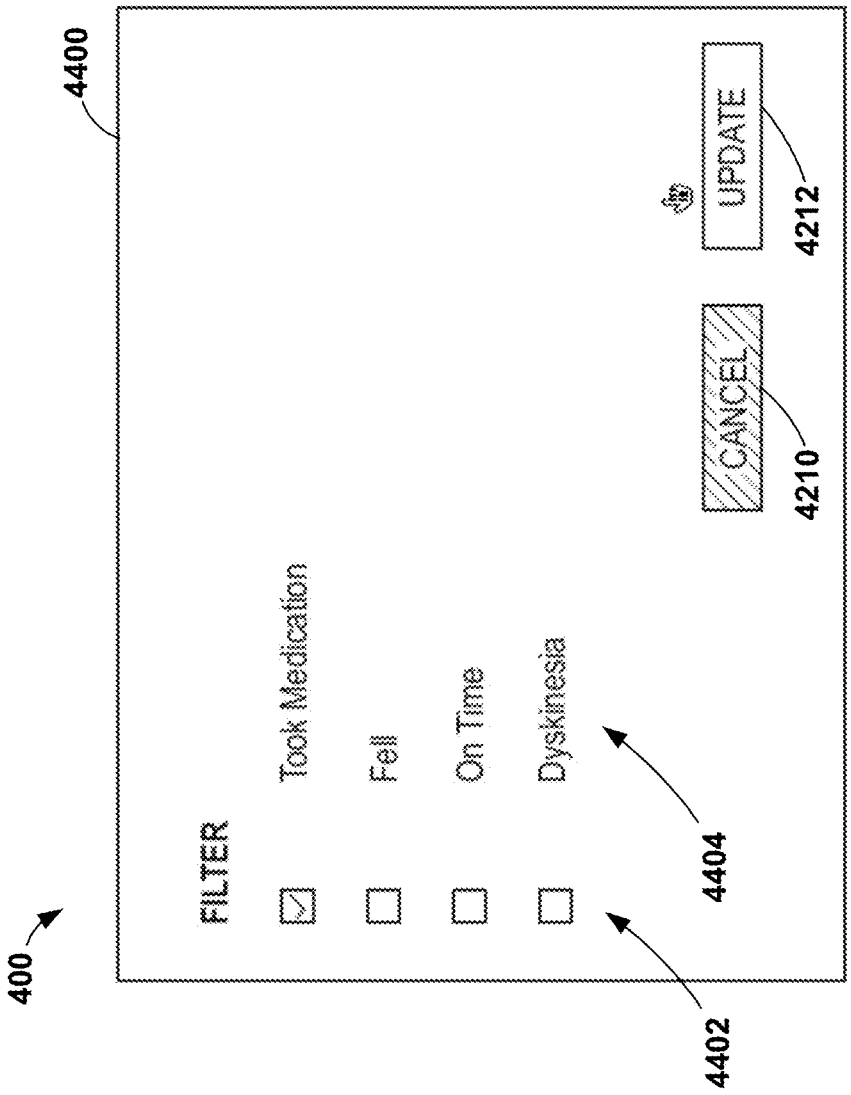

400
4400
FILTER
Took Medication
Fell
On Time
Dyskinesia
4402
4404
CANCEL
4210
UPDATE
4212

FIG. 44

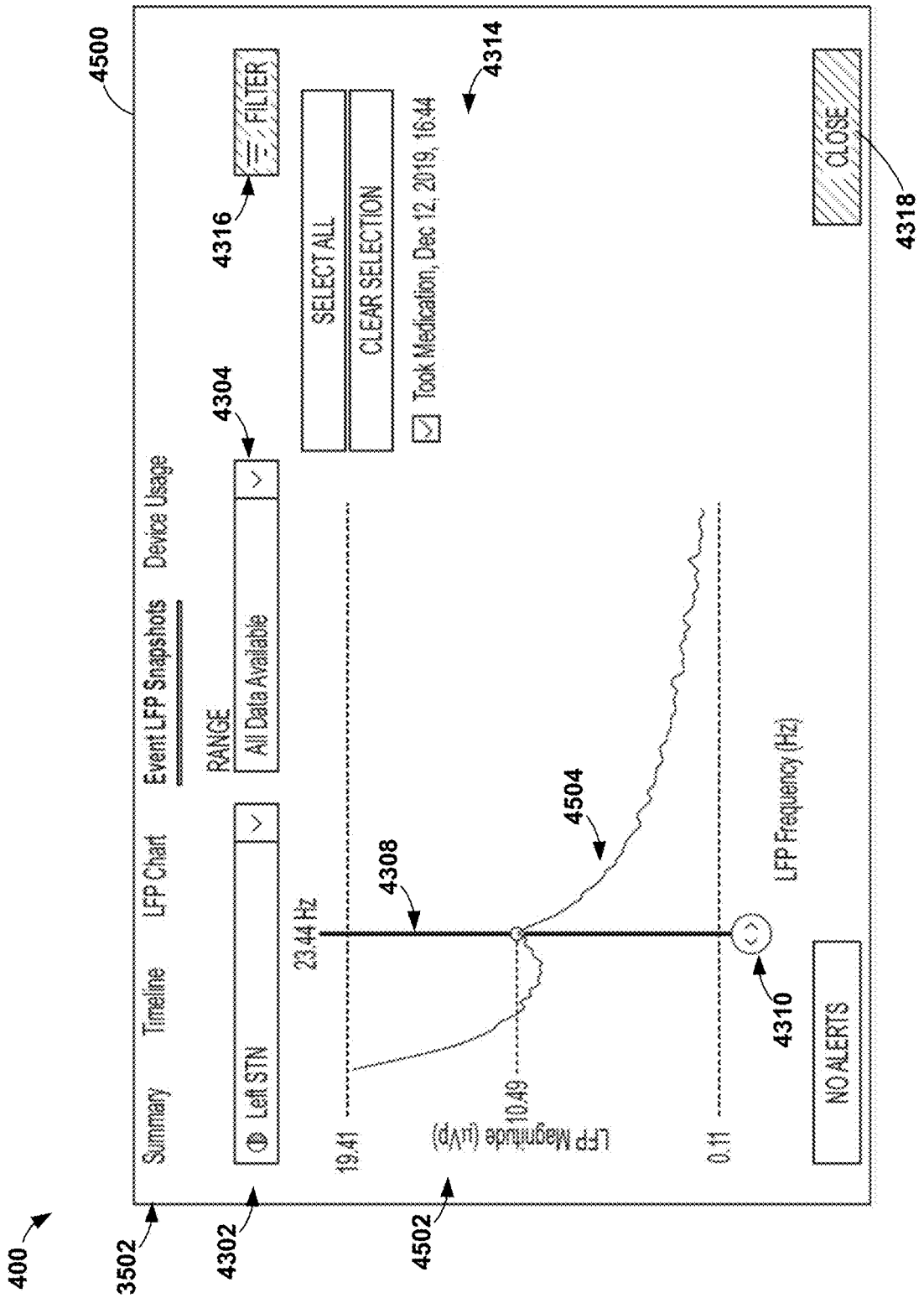

400
3502
4302
4502
4500
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
RANGE
All Data Available
4304
FILTER
4316
SELECT ALL
CLEAR SELECTION
Took Medication, Dec 12, 2019, 16:44
4314
CLOSE
4318
23.44 Hz
4308
4504
19.41
10.49
0.11
LFP Magnitude (uVp)
LFP Frequency (Hz)
4310
NO ALERTS

FIG. 45

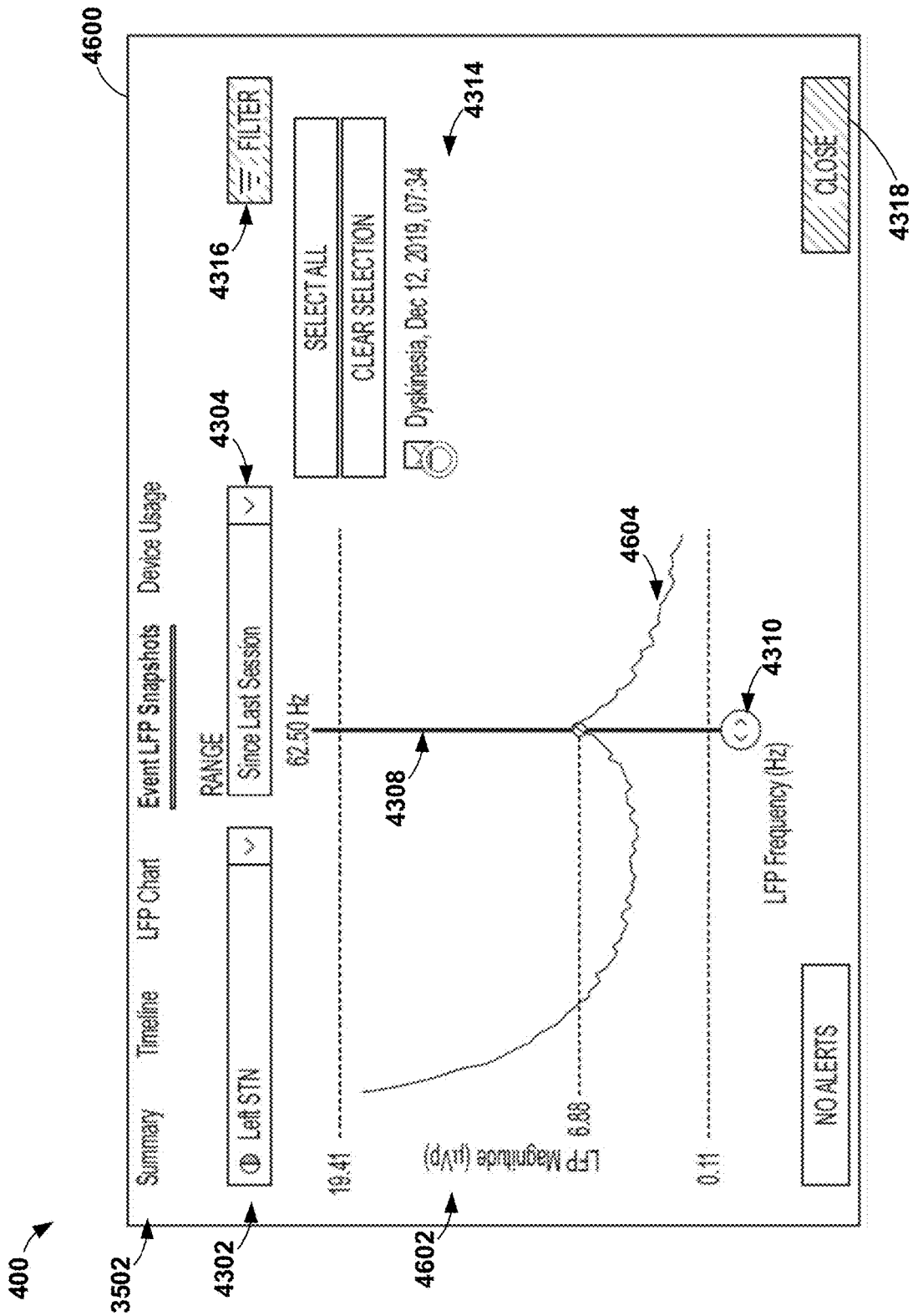

400
4600
3502
4302
4602
4304
4316
4314
4308
4604
4310
4318
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
RANGE
Since Last Session
62.50 Hz
FILTER
SELECT ALL
CLEAR SELECTION
Dyskinesia, Dec 12, 2019, 07:34
CLOSE
19.41
6.86
0.11
LFP Magnitude (µV/p)
LFP Frequency (Hz)
NO ALERTS

FIG. 46

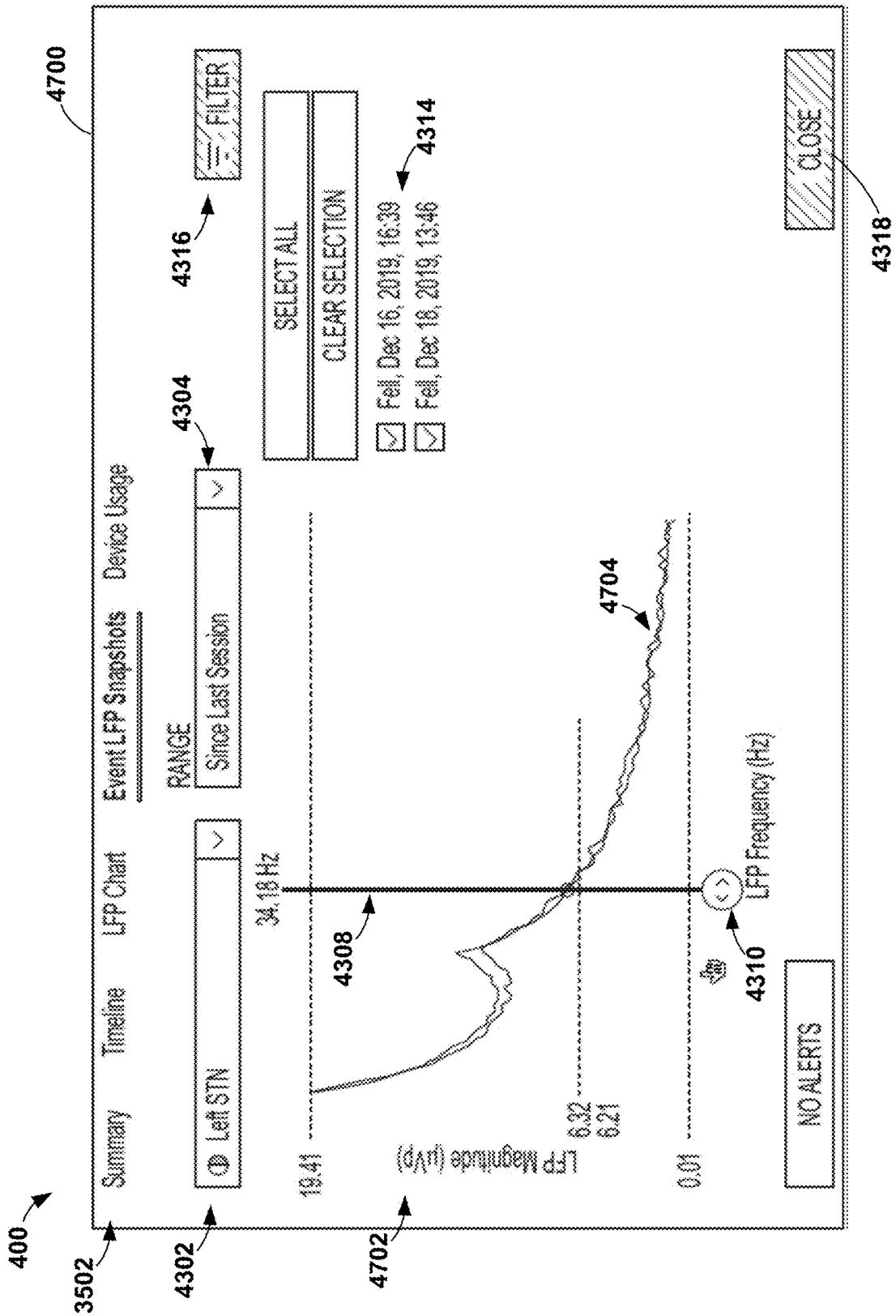

400
3502
4302
4702
4700
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
RANGE
Since Last Session
4304
4316
FILTER
SELECT ALL
CLEAR SELECTION
Fel, Dec 16, 2019, 16:39
Fel, Dec 18, 2019, 13:46
4314
CLOSE
4318
34.18 Hz
4308
4704
19.41
6.32
6.21
0.01
LFP Magnitude (uVp)
LFP Frequency (Hz)
4310
NO ALERTS

FIG. 47

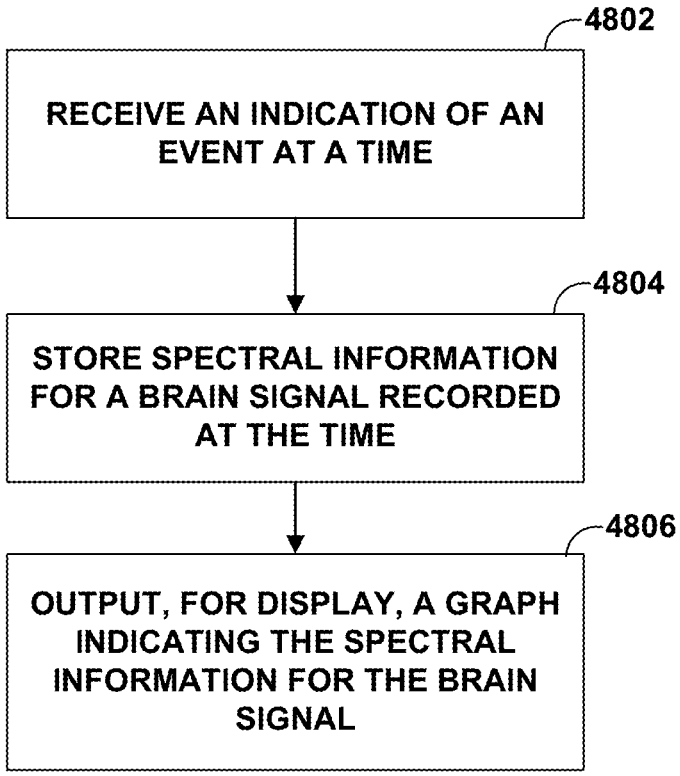

4802
RECEIVE AN INDICATION OF AN EVENT AT A TIME
4804
STORE SPECTRAL INFORMATION FOR A BRAIN SIGNAL RECORDED AT THE TIME
4806
OUTPUT, FOR DISPLAY, A GRAPH INDICATING THE SPECTRAL INFORMATION FOR THE BRAIN SIGNAL

FIG. 48

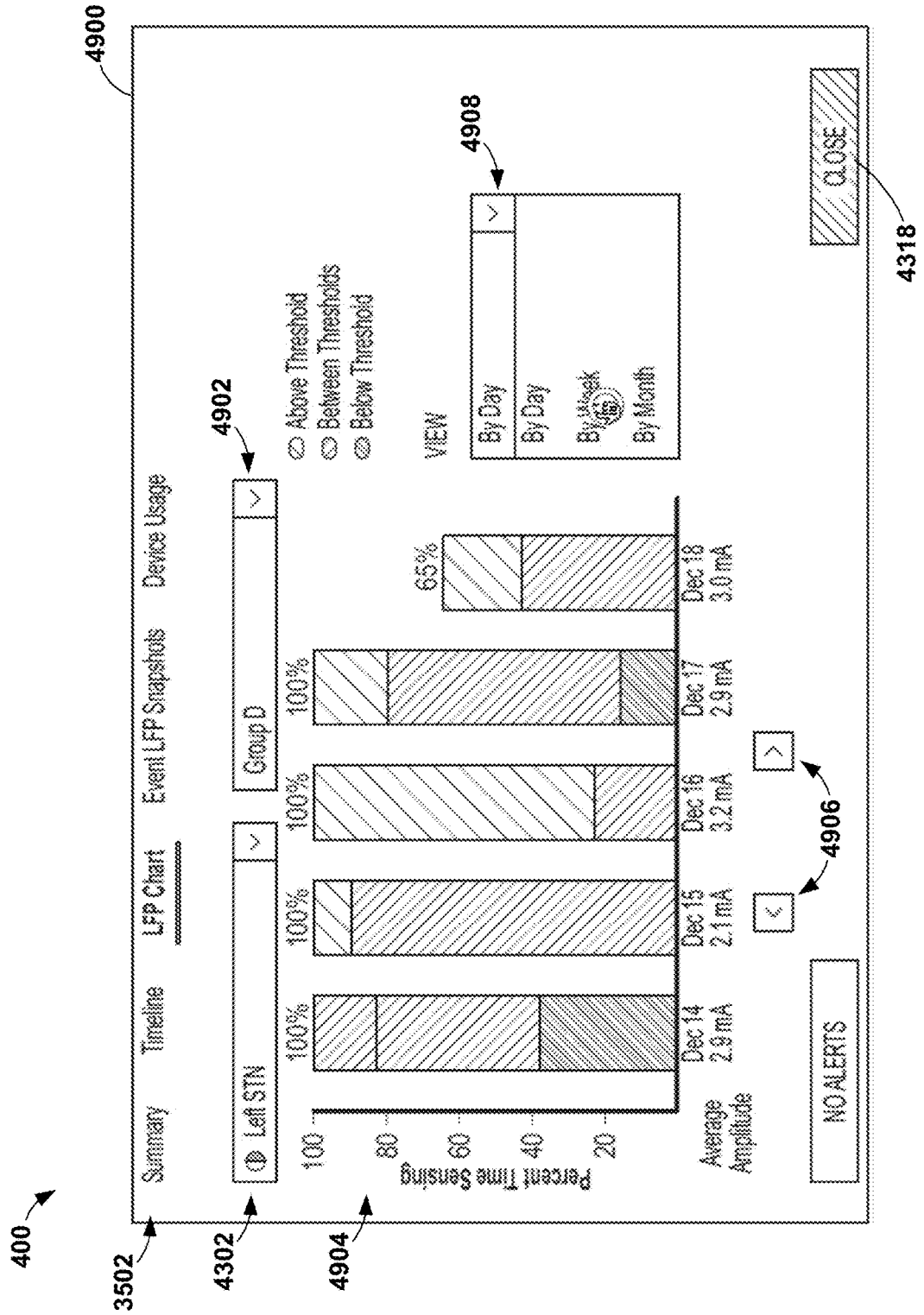

400
3502
4302
4904
4900
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Group D
4902
Above Threshold
Between Thresholds
Below Threshold
VIEW
By Day
By Day
By Week
By Month
4908
CLOSE
4318
Percent Time Sensing
100
80
60
40
20
Average Amplitude
100%
Dec 14
2.9 mA
100%
Dec 15
2.1 mA
100%
Dec 16
3.2 mA
100%
Dec 17
2.9 mA
65%
Dec 18
3.0 mA
4906
NO ALERTS

FIG. 49

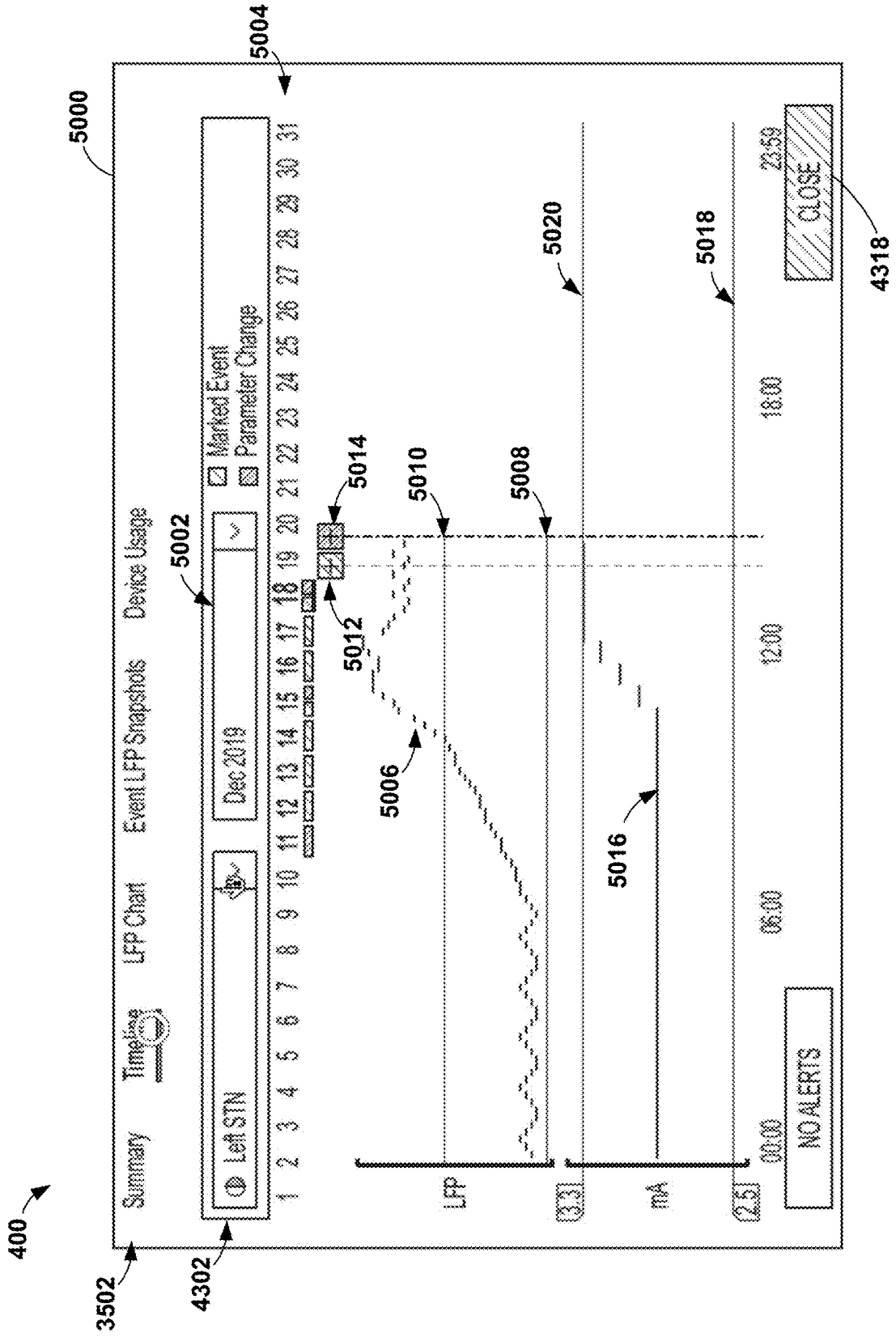

400
3502
4302
5000
5004
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Dec 2019
Marked Event
Parameter Change
5002
5014
5010
5008
5012
5006
5016
5020
5018
LFP
3.3
mA
2.5
00:00
06:00
12:00
18:00
23:59
NO ALERTS
CLOSE
4318

FIG. 50

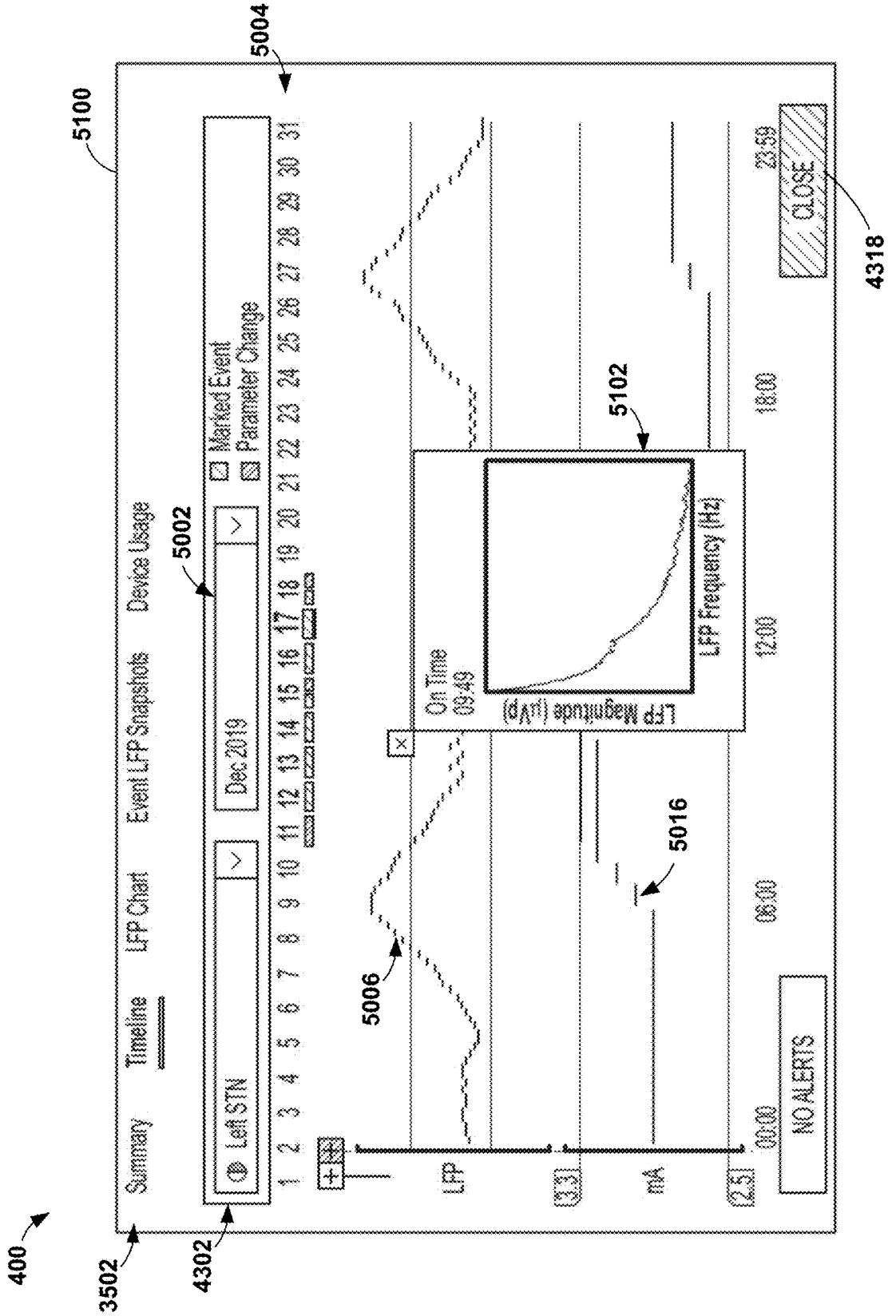

400
3502
4302
5100
5004
5002
5006
5102
5016
4318
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Dec 2019
Marked Event
Parameter Change
On Time
09:49
LFP Magnitude (μVp)
LFP Frequency (Hz)
LFP
3.3
mA
2.5
00:00
06:00
12:00
18:00
23:59
CLOSE
NO ALERTS

FIG. 51

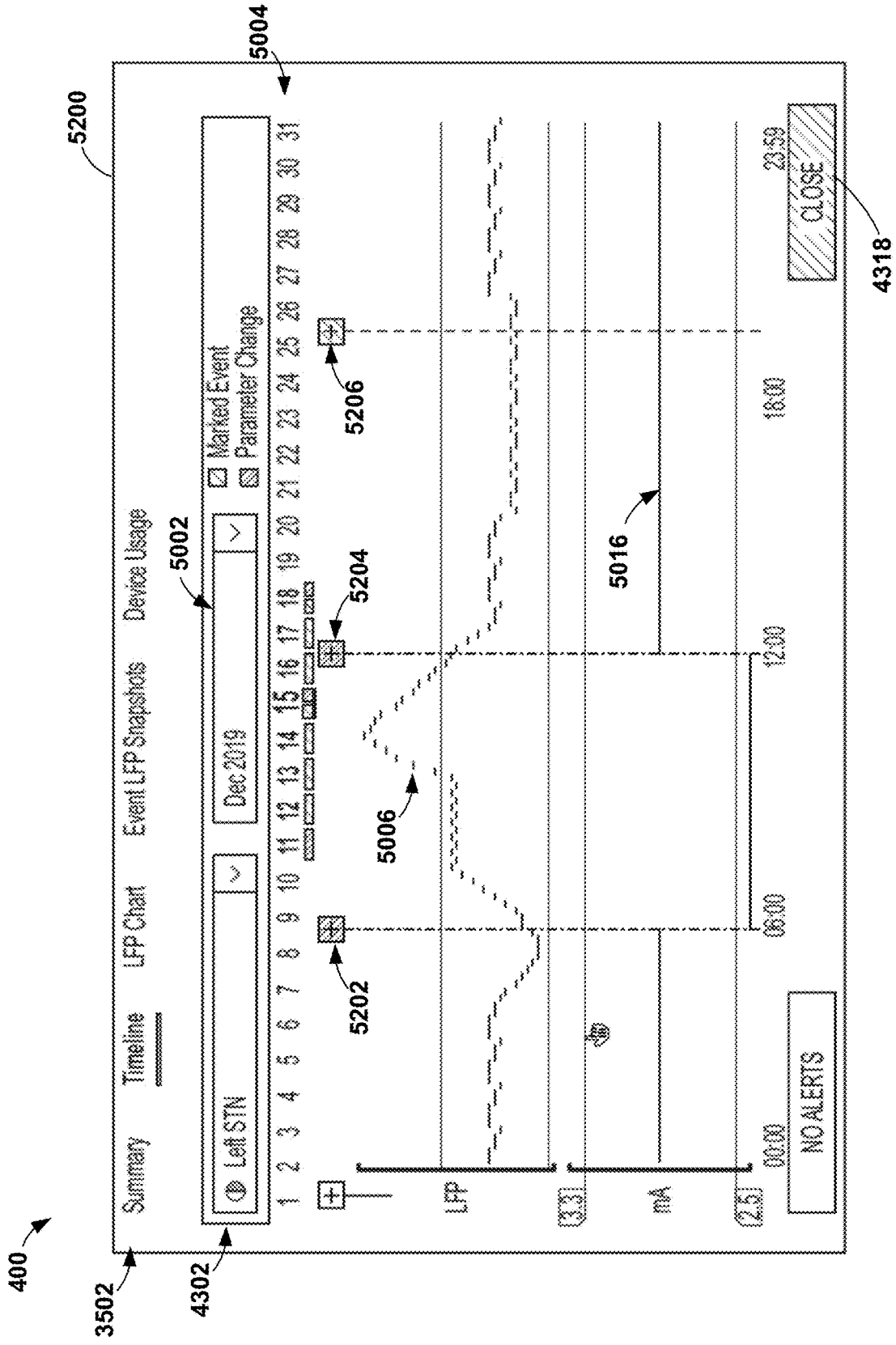

400
3502
4302
5200
5004
5002
5202
5204
5206
5006
5016
4318
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Dec 2019
Marked Event
Parameter Change
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
LFP
mA
3.3
2.5
00:00
06:00
12:00
18:00
23:59
CLOSE
NO ALERTS

FIG. 52

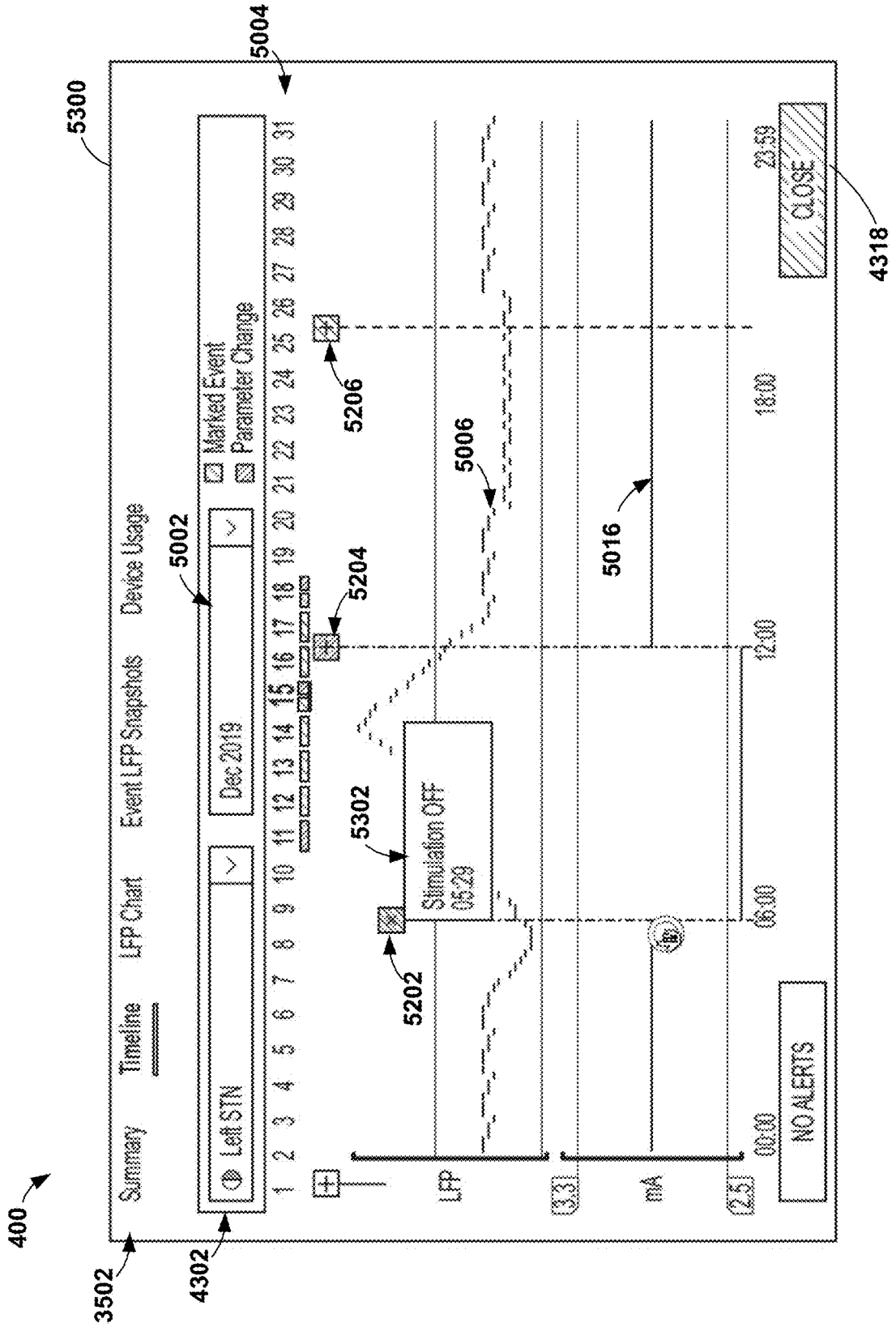

400
3502
4302
5300
5004
5002
5006
5016
5204
5206
5202
5302
4318
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Dec 2019
Marked Event
Parameter Change
Stimulation OFF
05:28
LFP
mA
3.3
2.5
00:00
06:00
12:00
18:00
23:59
CLOSE
NO ALERTS

FIG. 53

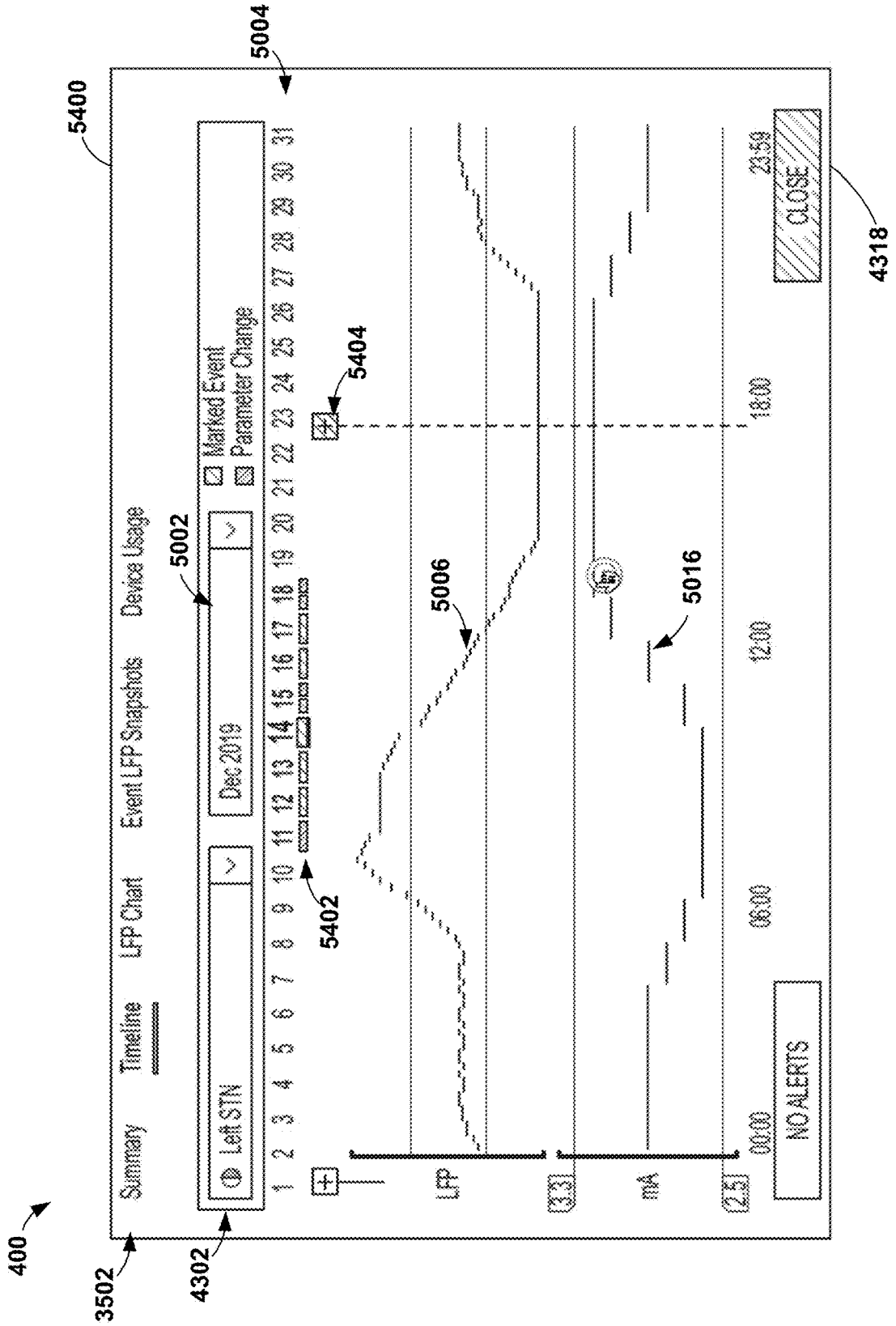

400
3502
4302
5400
5004
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Dec 2019
Marked Event
Parameter Change
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
5002
5402
5404
5006
5016
LFP
mA
3.3
2.5
00:00
06:00
12:00
18:00
23:59
NO ALERTS
CLOSE
4318

FIG. 54

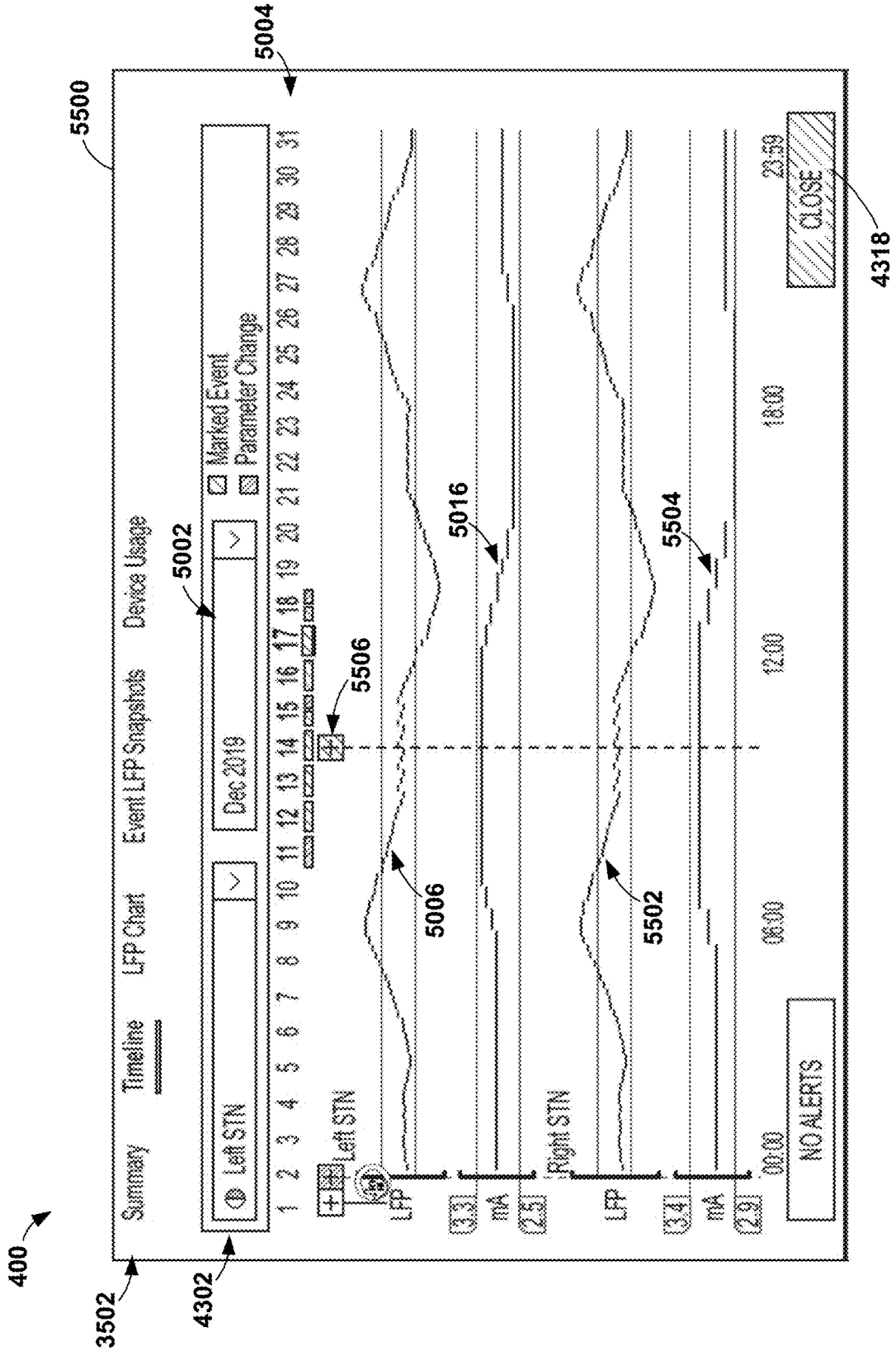

400
3502
4302
5500
5004
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
Left STN
Dec 2019
Marked Event
Parameter Change
5002
5506
5016
5504
5006
5502
Left STN
Right STN
LFP
mA
3.3
2.5
3.4
2.9
00:00
06:00
12:00
18:00
23:59
NO ALERTS
CLOSE
4318

FIG. 55

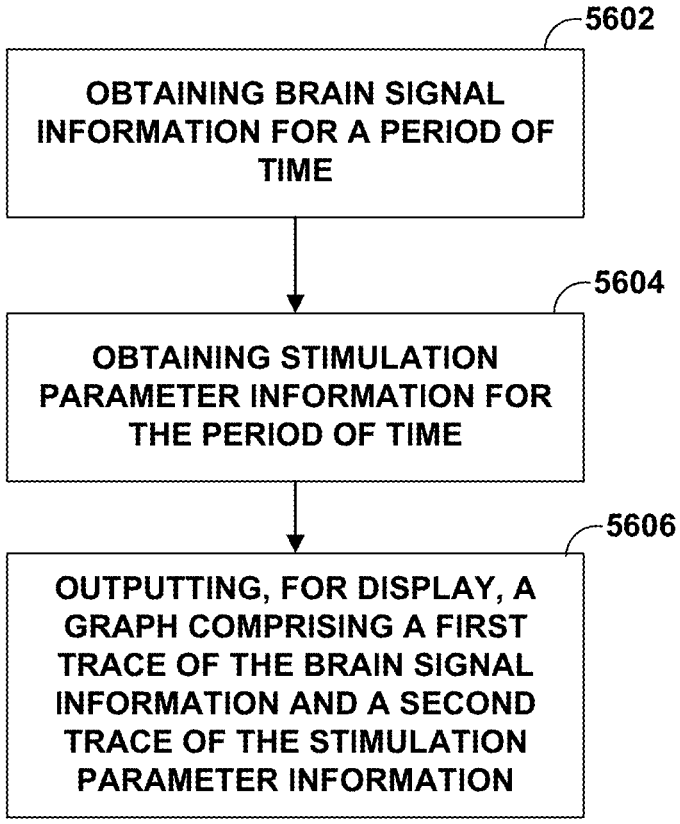

5602
OBTAINING BRAIN SIGNAL INFORMATION FOR A PERIOD OF TIME
5604
OBTAINING STIMULATION PARAMETER INFORMATION FOR THE PERIOD OF TIME
5606
OUTPUTTING, FOR DISPLAY, A GRAPH COMPRISING A FIRST TRACE OF THE BRAIN SIGNAL INFORMATION AND A SECOND TRACE OF THE STIMULATION PARAMETER INFORMATION

FIG. 56

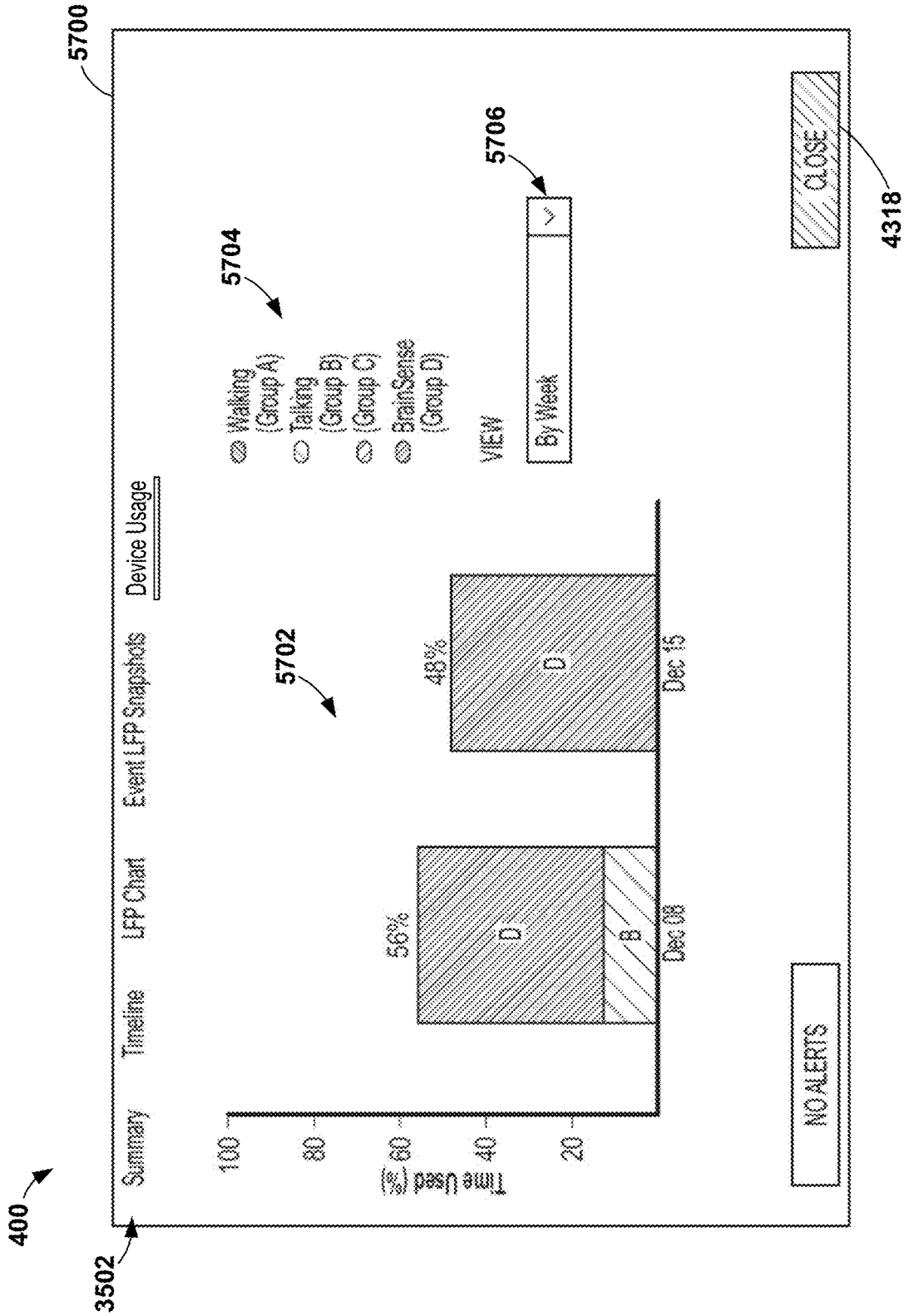

400
3502
5700
Summary
Timeline
LFP Chart
Event LFP Snapshots
Device Usage
5702
5704
Walking (Group A)
Talking (Group B)
(Group C)
BrainSense (Group D)
VIEW
By Week
5706
CLOSE
4318
Time Used (%)
100
80
60
40
20
56%
D
B
Dec 08
48%
D
Dec 15
NO ALERTS

FIG. 57

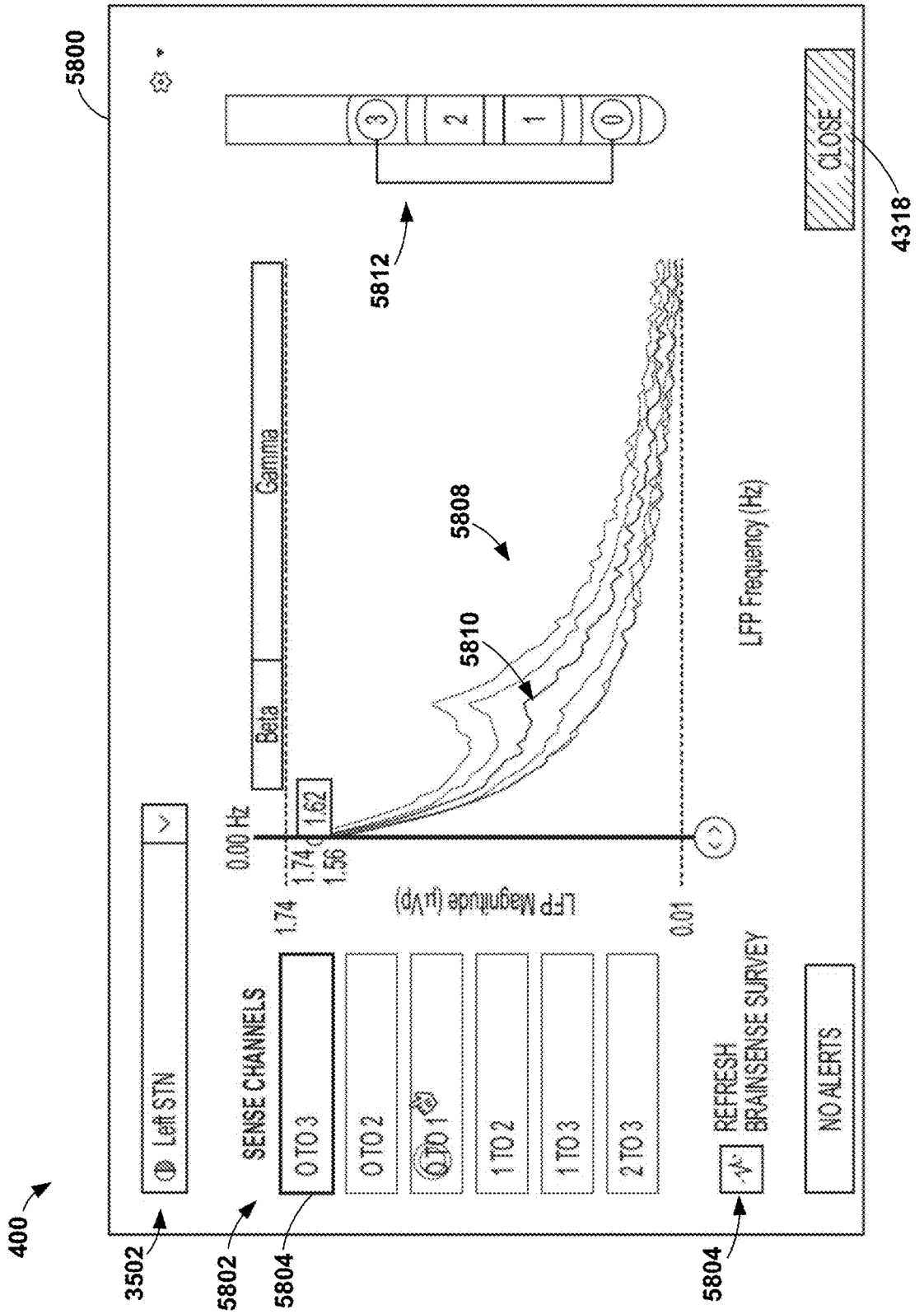

5800
3
2
1
0
5812
CLOSE
4318
Gamma
Beta
5808
5810
0.00 Hz
1.62
1.74
1.56
1.74
LFP Magnitude (μVp)
0.01
LFP Frequency (Hz)
Left STN
SENSE CHANNELS
0 TO 3
0 TO 2
0 TO 1
1 TO 2
1 TO 3
2 TO 3
REFRESH
BRAINSENSE SURVEY
NO ALERTS
400
3502
5802
5804
5804

FIG. 58

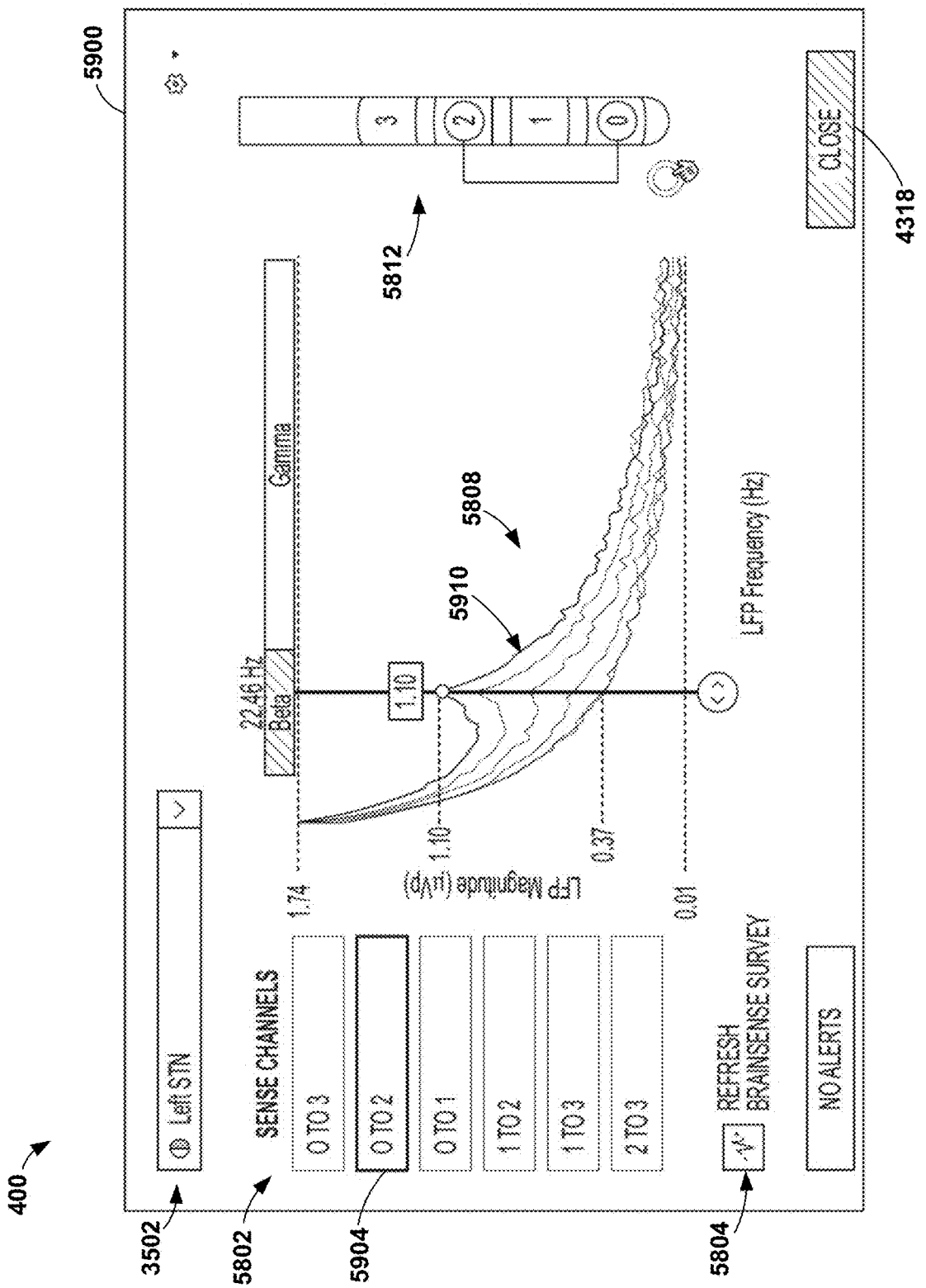

400
5900
3502
5802
5904
5804
4318
5812
5808
5910
Left STN
SENSE CHANNELS
0 TO 3
0 TO 2
0 TO 1
1 TO 2
1 TO 3
2 TO 3
Gamma
22.46 Hz
Beta
1.10
1.74
1.10
0.37
0.01
LFP Magnitude (uVp)
LFP Frequency (Hz)
REFRESH
BRAINSENSE SURVEY
NO ALERTS
CLOSE
3
2
1
0

FIG. 59

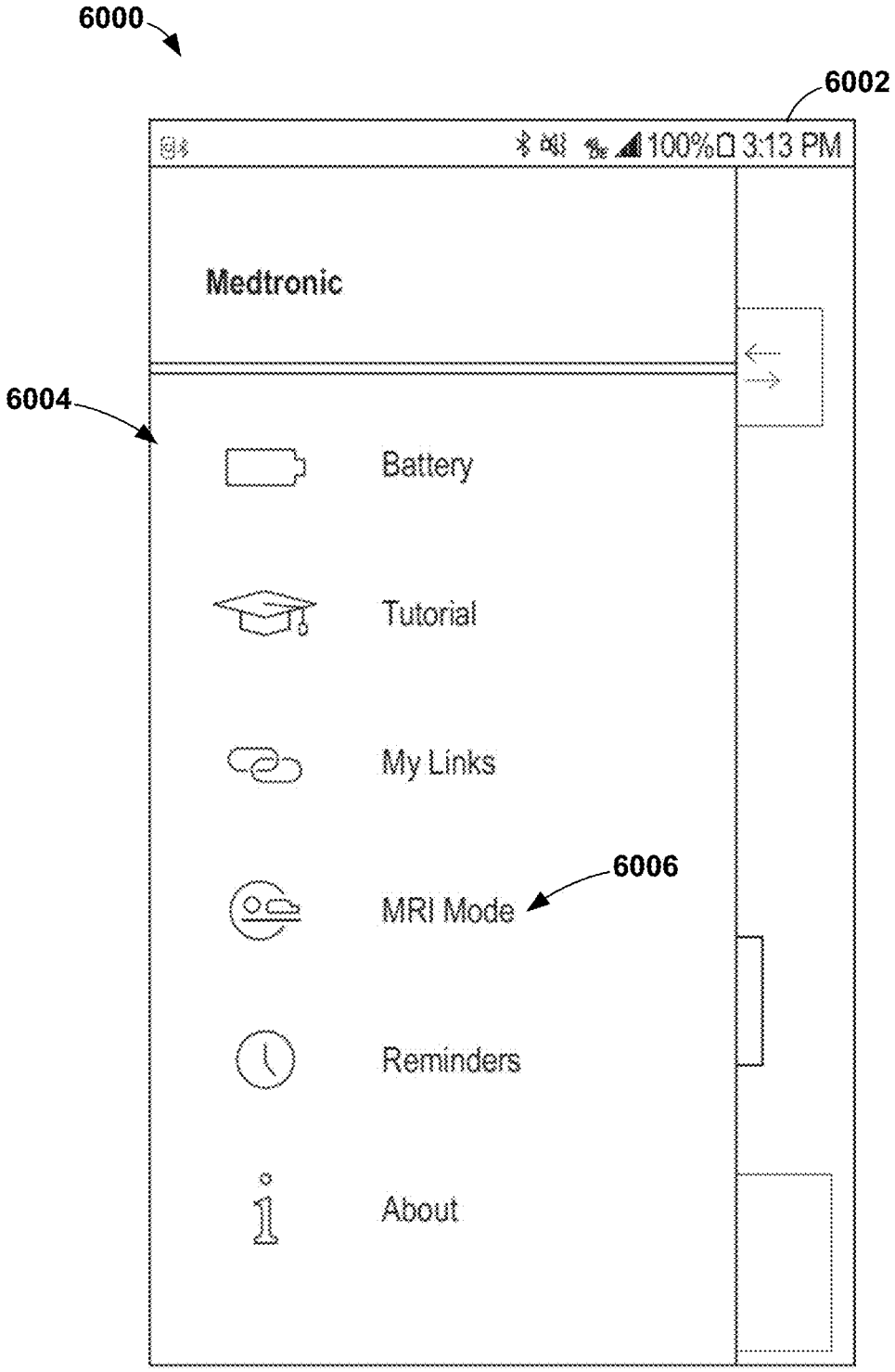

6000
6002
100% 3:13 PM
Medtronic
6004
Battery
Tutorial
My Links
6006
MRI Mode
Reminders
About

FIG. 60

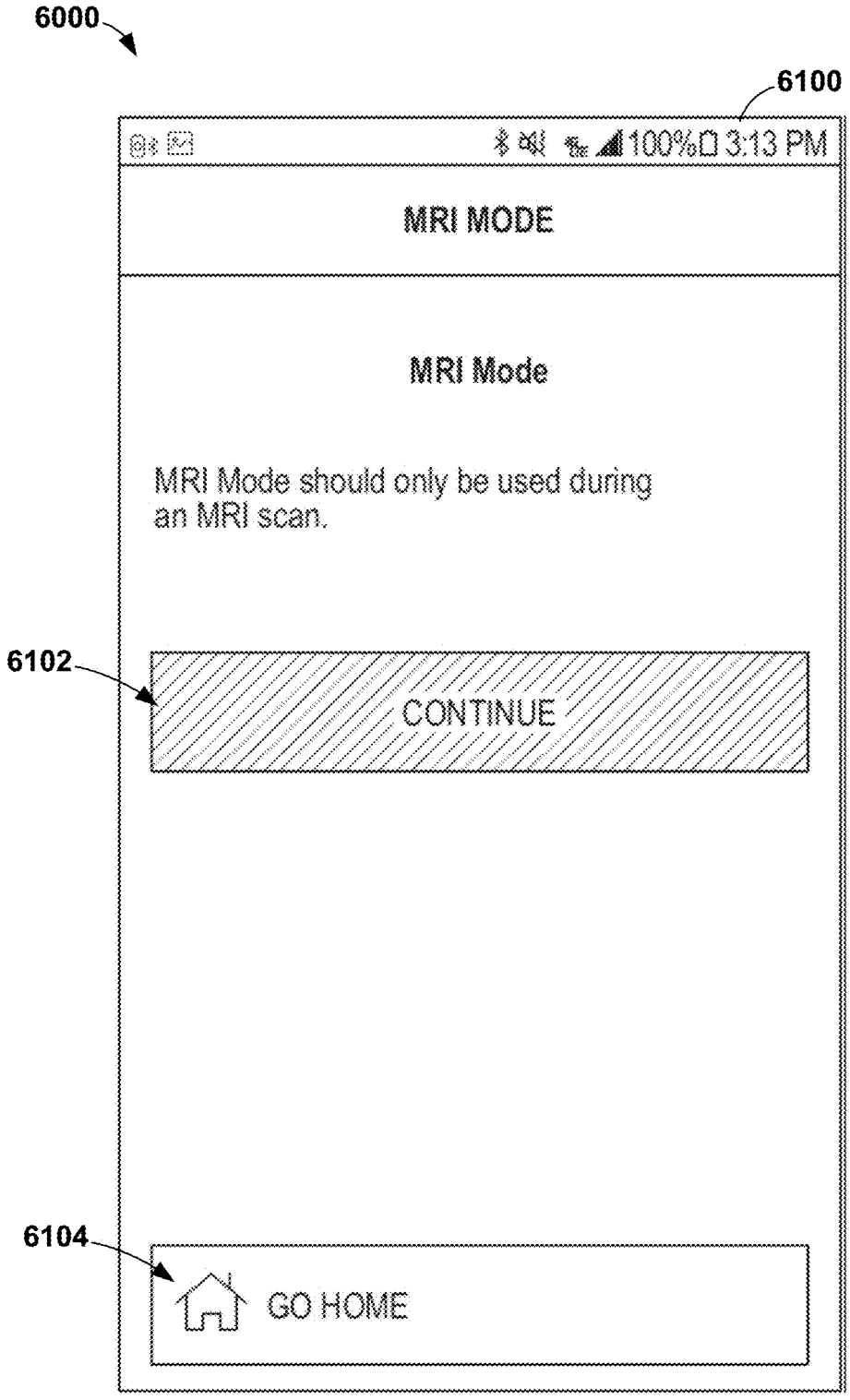

6000
6100
100% 3:13 PM
MRI MODE
MRI Mode
MRI Mode should only be used during an MRI scan.
6102
CONTINUE
6104
GO HOME

FIG. 61

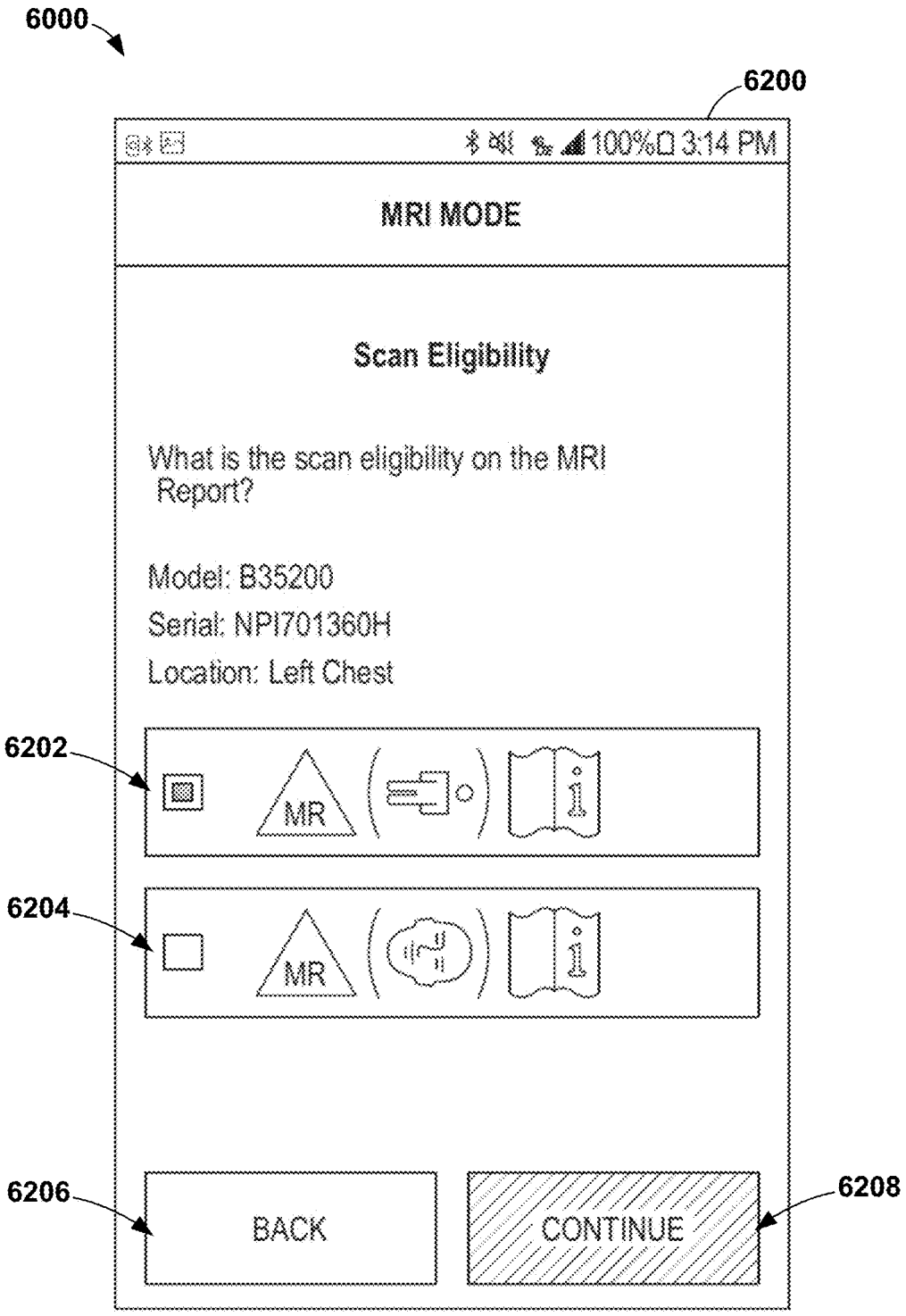

6000
6200
100% 3:14 PM
MRI MODE
Scan Eligibility
What is the scan eligibility on the MRI Report?
Model: B35200
Serial: NPI701360H
Location: Left Chest
6202
MR
6204
MR
6206
BACK
CONTINUE
6208

FIG. 62

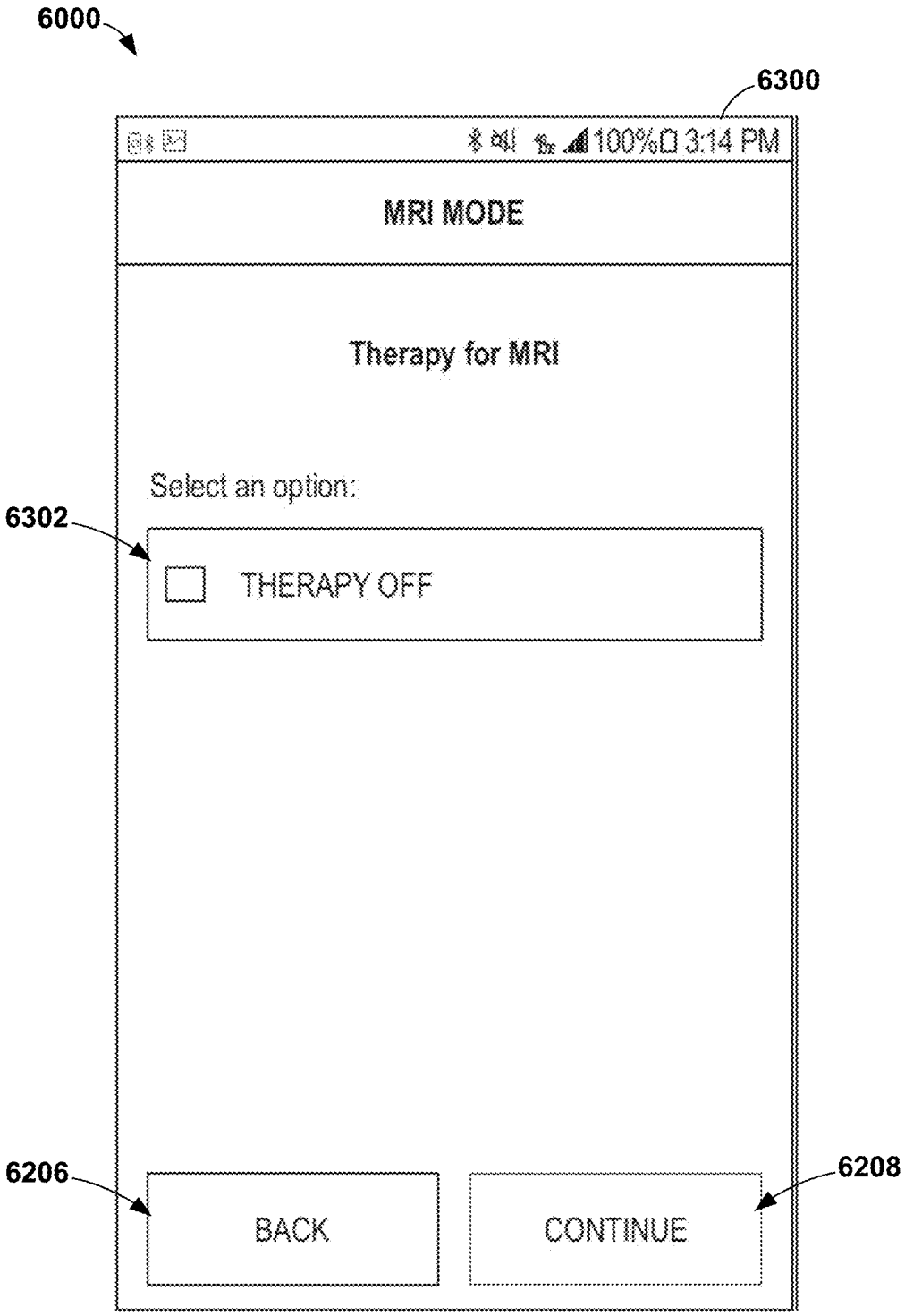

6000
6300
100% 3:14 PM
MRI MODE
Therapy for MRI
Select an option:
6302
THERAPY OFF
6206
BACK
CONTINUE
6208

FIG. 63

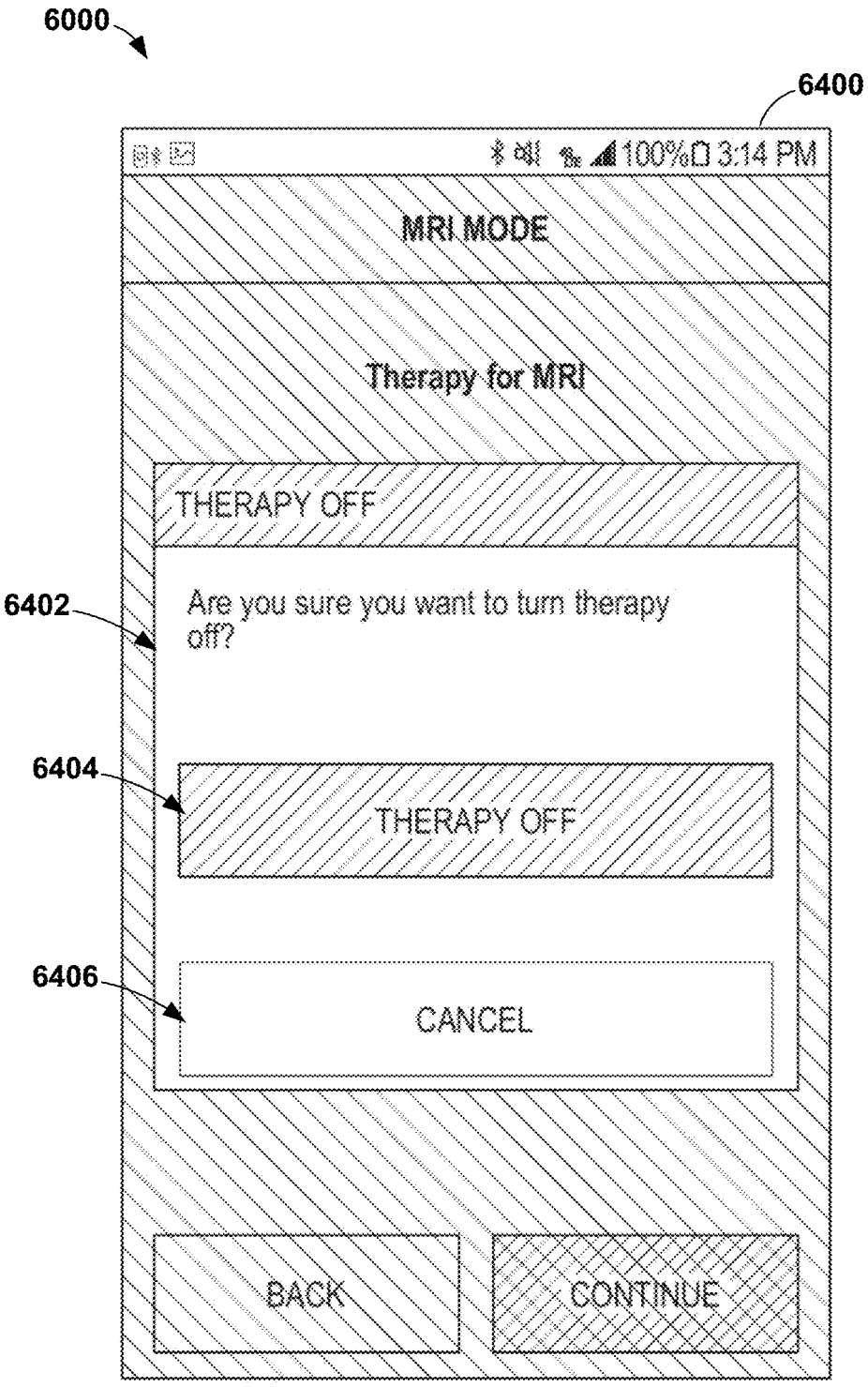

6000
6400
100% 3:14 PM
MRI MODE
Therapy for MRI
THERAPY OFF
6402
Are you sure you want to turn therapy off?
6404
THERAPY OFF
6406
CANCEL
BACK
CONTINUE

FIG. 64

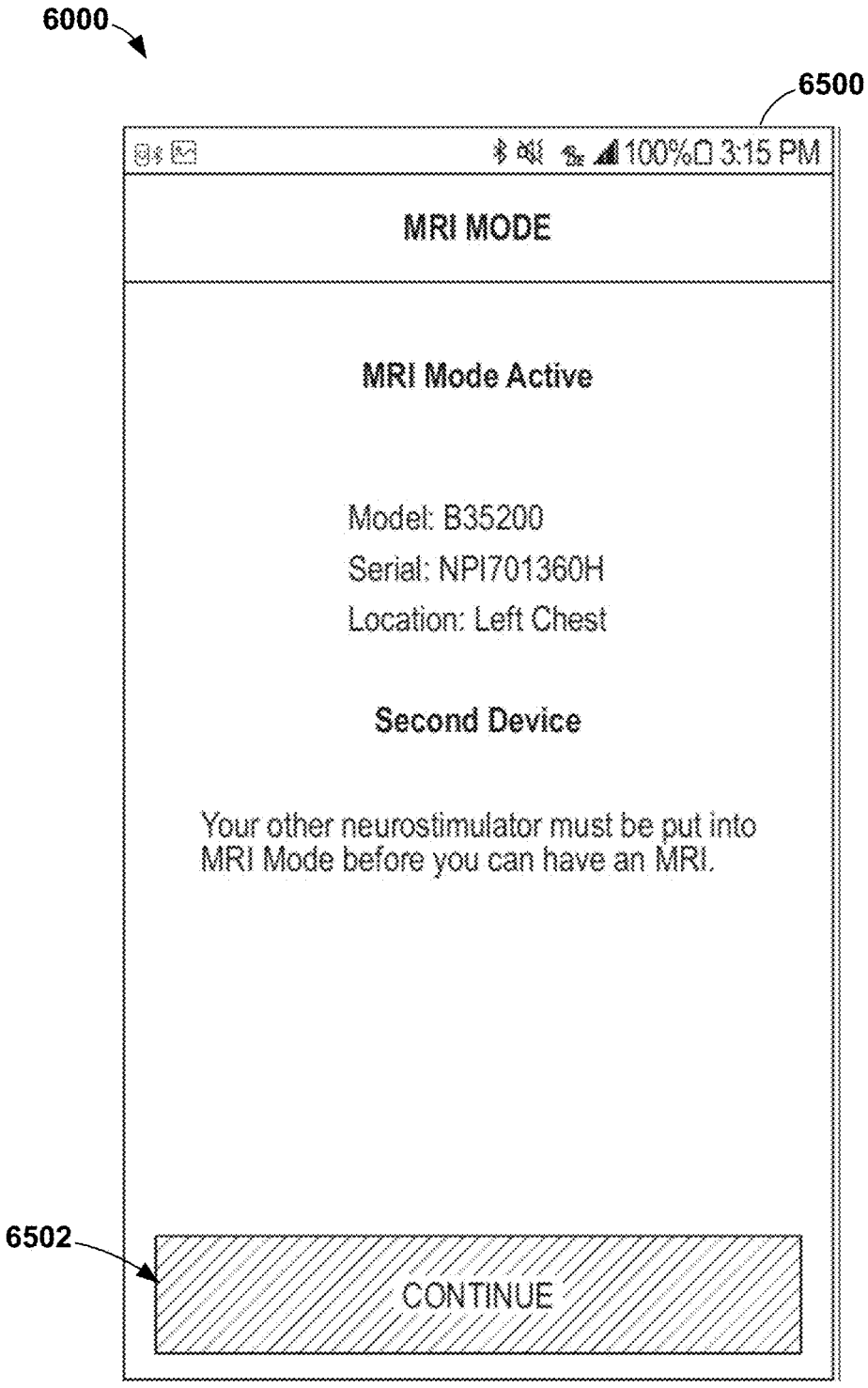

6000
6500
100% 3:15 PM
MRI MODE
MRI Mode Active
Model: B35200
Serial: NPI701360H
Location: Left Chest
Second Device
Your other neurostimulator must be put into MRI Mode before you can have an MRI.
6502
CONTINUE

FIG. 65

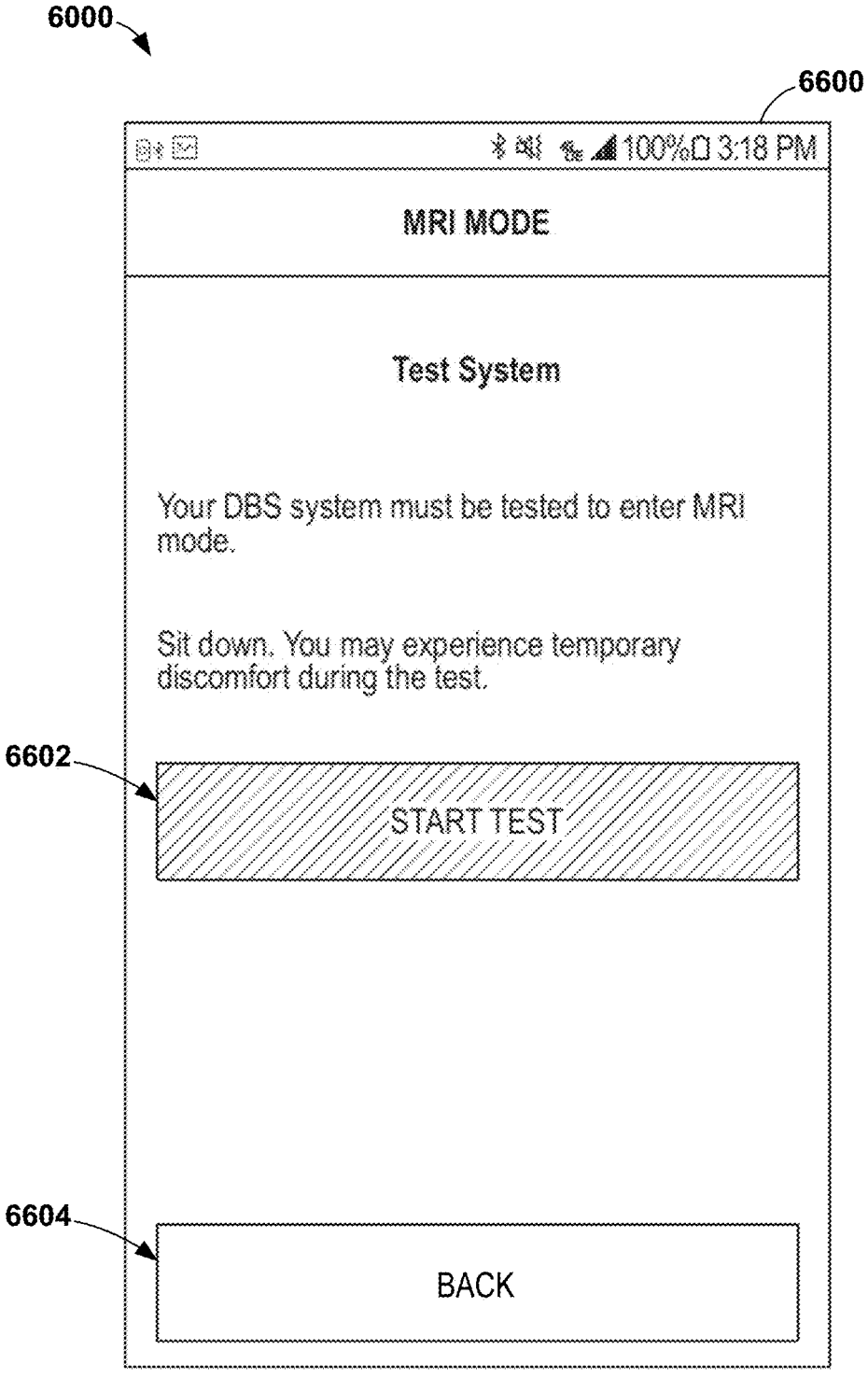

6000
6600
100% 3:18 PM
MRI MODE
Test System
Your DBS system must be tested to enter MRI mode.
Sit down. You may experience temporary discomfort during the test.
6602
START TEST
6604
BACK

FIG. 66

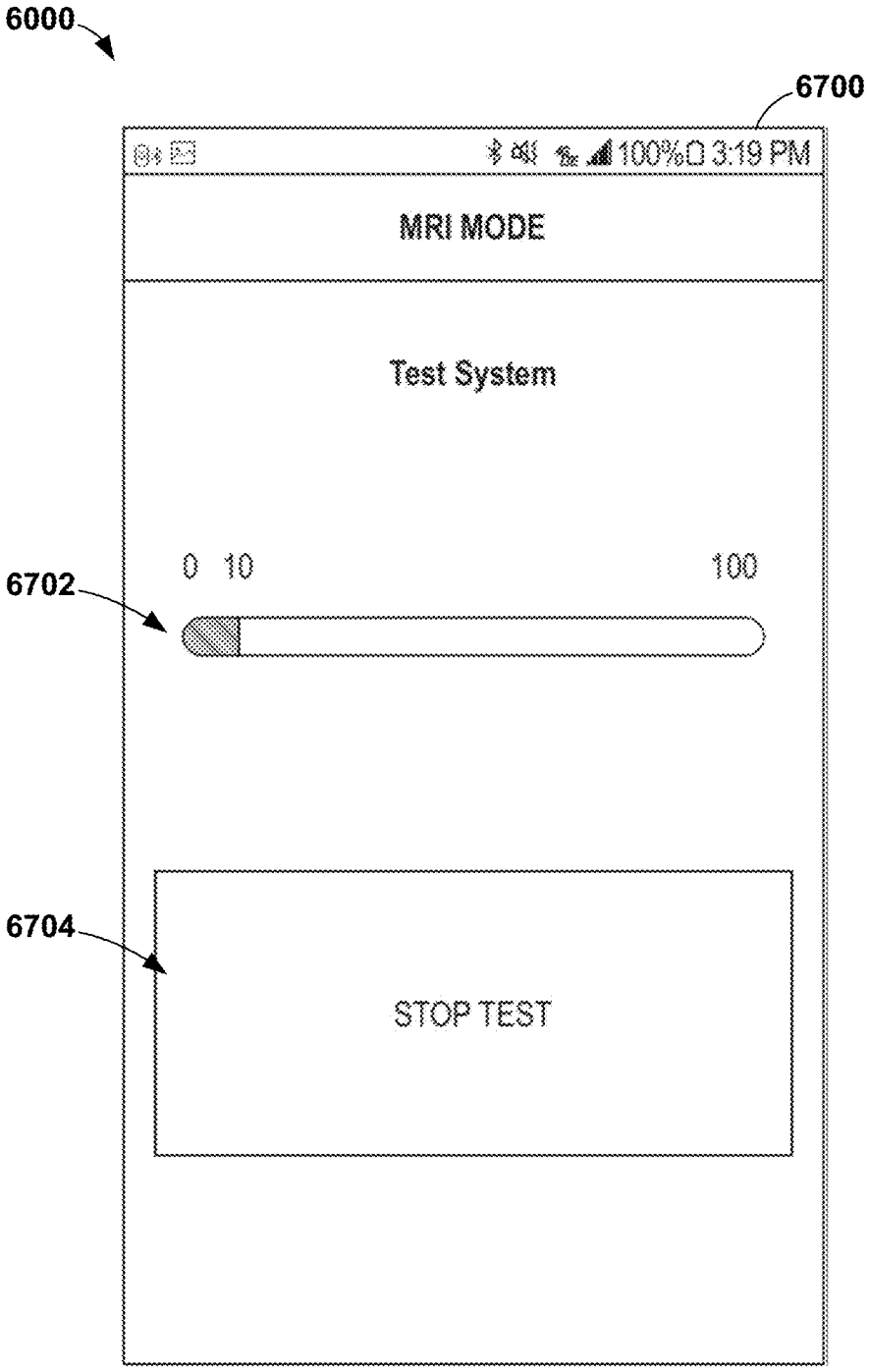

6000
6700
100% 3:19 PM
MRI MODE
Test System
0 10
100
6702
6704
STOP TEST

FIG. 67

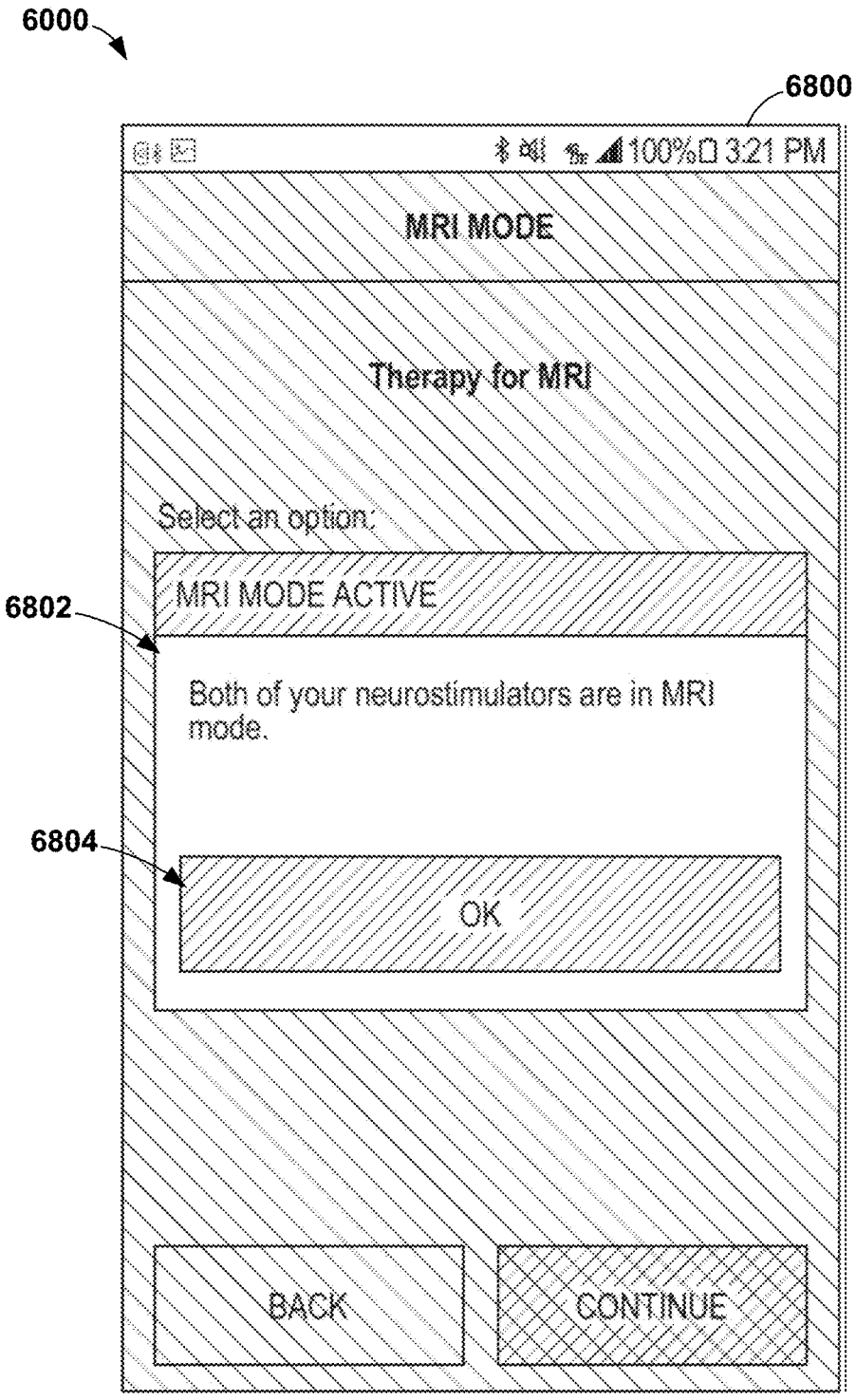

6000
6800
100% 3:21 PM
MRI MODE
Therapy for MRI
Select an option:
MRI MODE ACTIVE
6802
Both of your neurostimulators are in MRI mode.
6804
OK
BACK
CONTINUE

FIG. 68

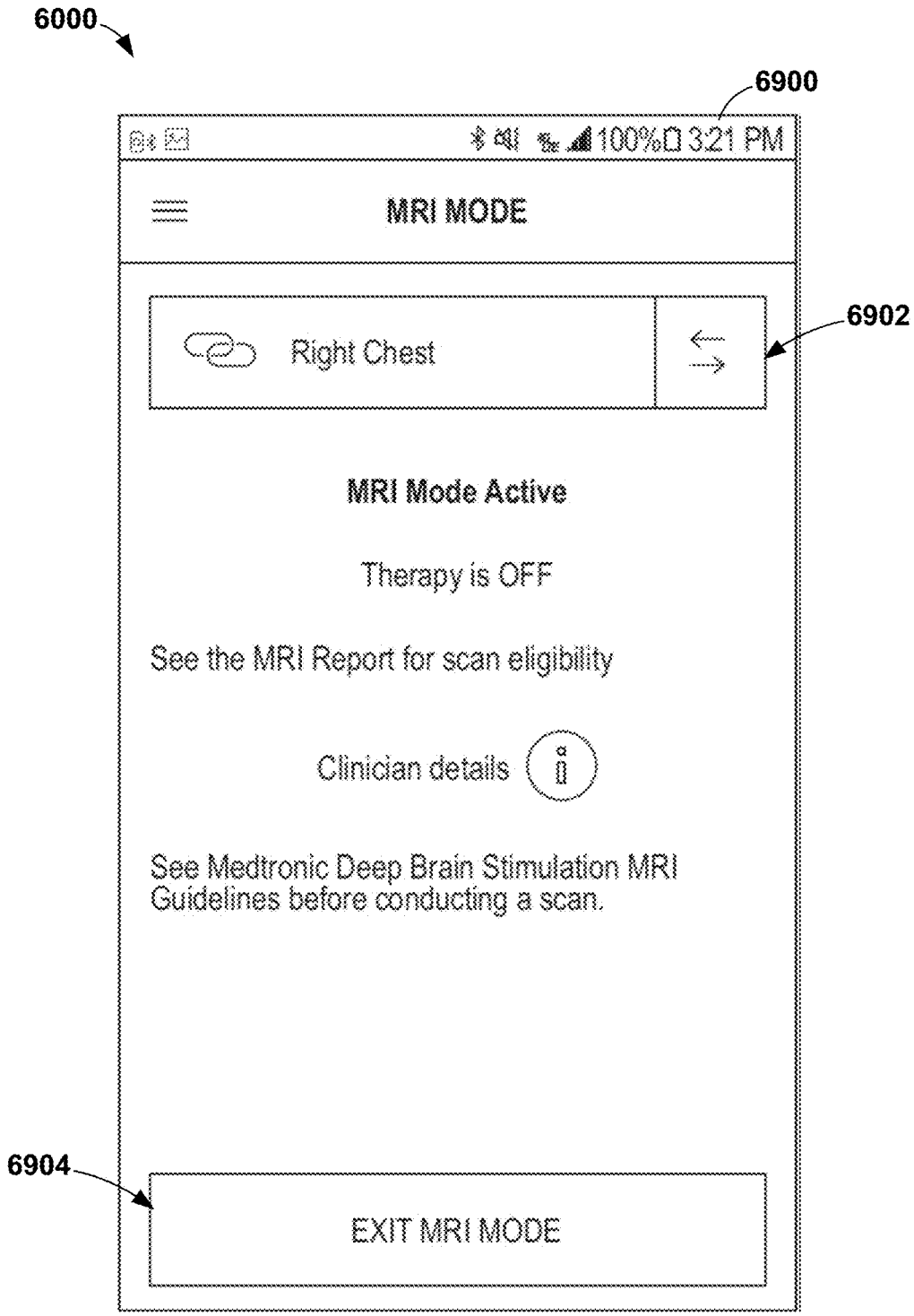

6000
6900
100% 3:21 PM
MRI MODE
Right Chest
6902
MRI Mode Active
Therapy is OFF
See the MRI Report for scan eligibility
Clinician details
See Medtronic Deep Brain Stimulation MRI Guidelines before conducting a scan.
6904
EXIT MRI MODE

FIG. 69

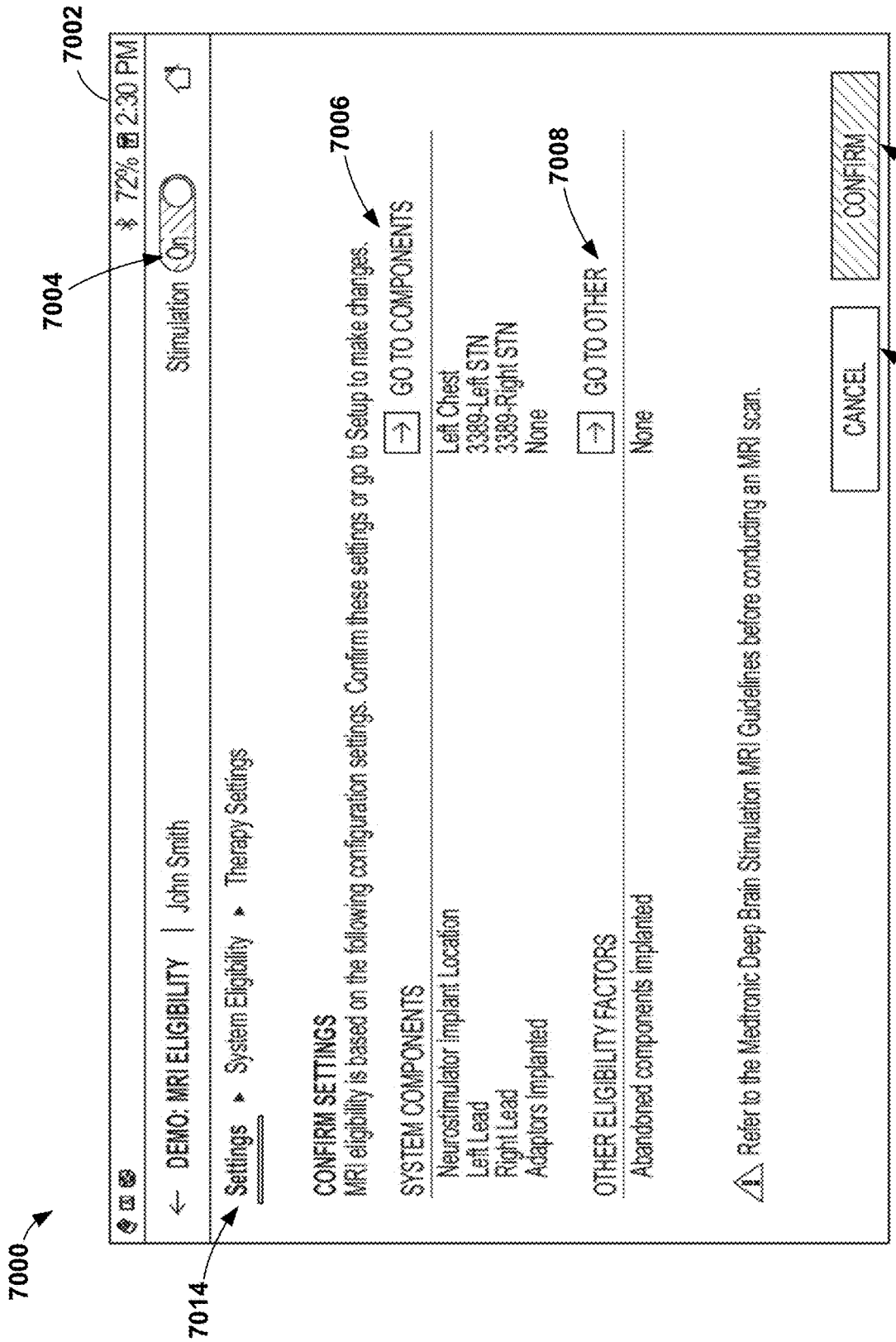

7000
7002
7004
7006
7008
7010
7012
7014
72% 2:30 PM
DEMO: MRI ELIGIBILITY | John Smith
Stimulation On
Settings • System Eligibility • Therapy Settings
CONFIRM SETTINGS
MRI eligibility is based on the following configuration settings. Confirm these settings or go to Setup to make changes.
SYSTEM COMPONENTS
GO TO COMPONENTS
Neurostimulator implant Location
Left Lead
Right Lead
Adaptors implanted
Left Chest
3389-Left STN
3389-Right STN
None
OTHER ELIGIBILITY FACTORS
GO TO OTHER
Abandoned components implanted
None
Refer to the Medtronic Deep Brain Stimulation MRI Guidelines before conducting an MRI scan.
CANCEL
CONFIRM

FIG. 70

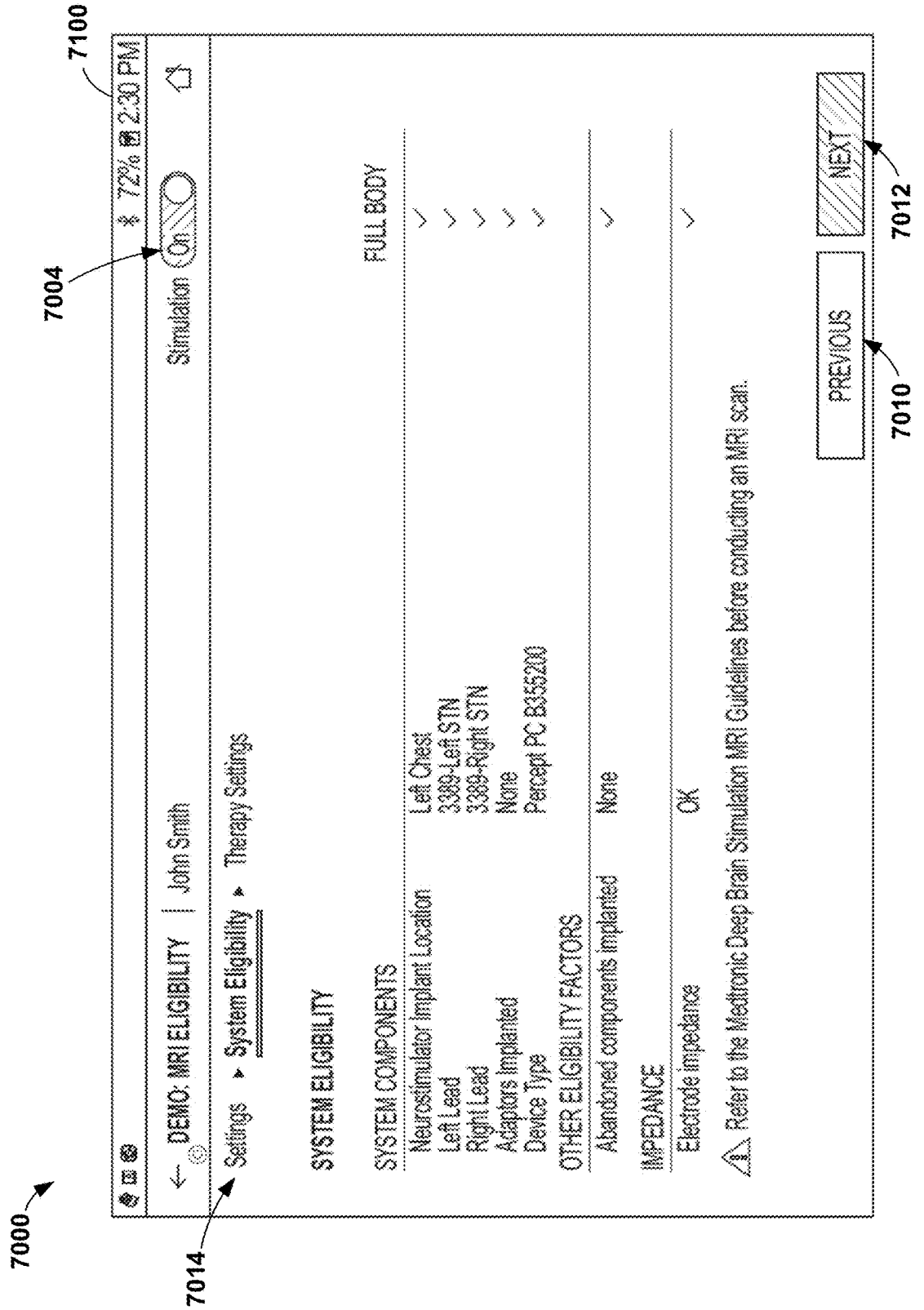

7000
7100
7004
7014
7010
7012
72% 2:30 PM
DEMO: MRI ELIGIBILITY | John Smith
Stimulation On
Settings ▸ System Eligibility ▸ Therapy Settings
SYSTEM ELIGIBILITY
FULL BODY
SYSTEM COMPONENTS
Neurostimulator Implant Location
Left Chest
Left Lead
3389-Left STN
Right Lead
3389-Right STN
Adaptors Implanted
None
Device Type
Percept PC B35200
OTHER ELIGIBILITY FACTORS
Abandoned components implanted
None
IMPEDANCE
Electrode impedance
OK
Refer to the Medtronic Deep Brain Stimulation MRI Guidelines before conducting an MRI scan.
PREVIOUS
NEXT

FIG. 71

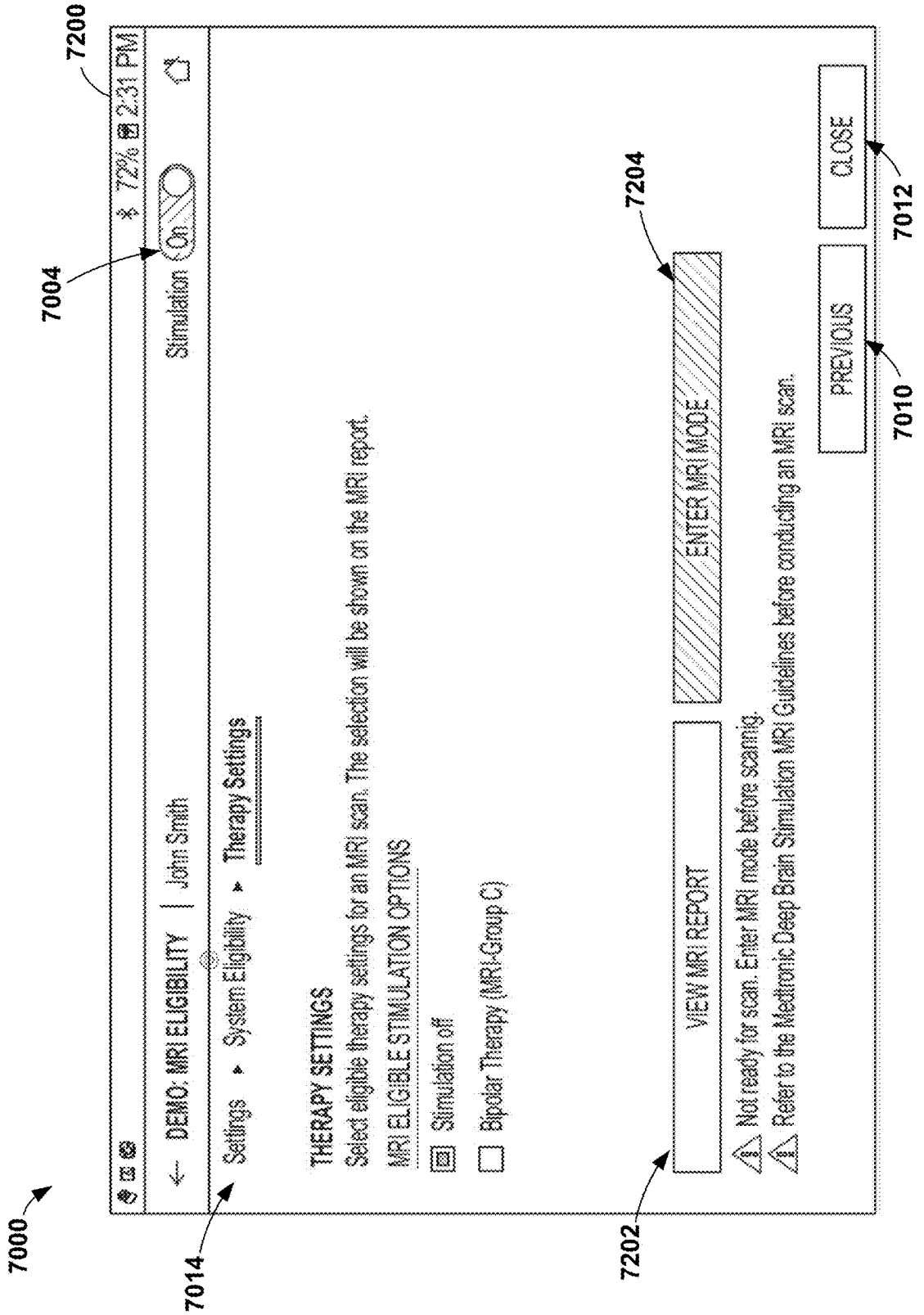

7000
7200
72% 2:31 PM
DEMO: MRI ELIGIBILITY | John Smith
7004
Stimulation On
Settings ▸ System Eligibility ▸ Therapy Settings
THERAPY SETTINGS
Select eligible therapy settings for an MRI scan. The selection will be shown on the MRI report.
MRI ELIGIBLE STIMULATION OPTIONS
Stimulation off
Bipolar Therapy (MRI-Group C)
7014
7202
VIEW MRI REPORT
7204
ENTER MRI MODE
Not ready for scan. Enter MRI mode before scanning.
Refer to the Medtronic Deep Brain Stimulation MRI Guidelines before conducting an MRI scan.
PREVIOUS
7010
CLOSE
7012

FIG. 72

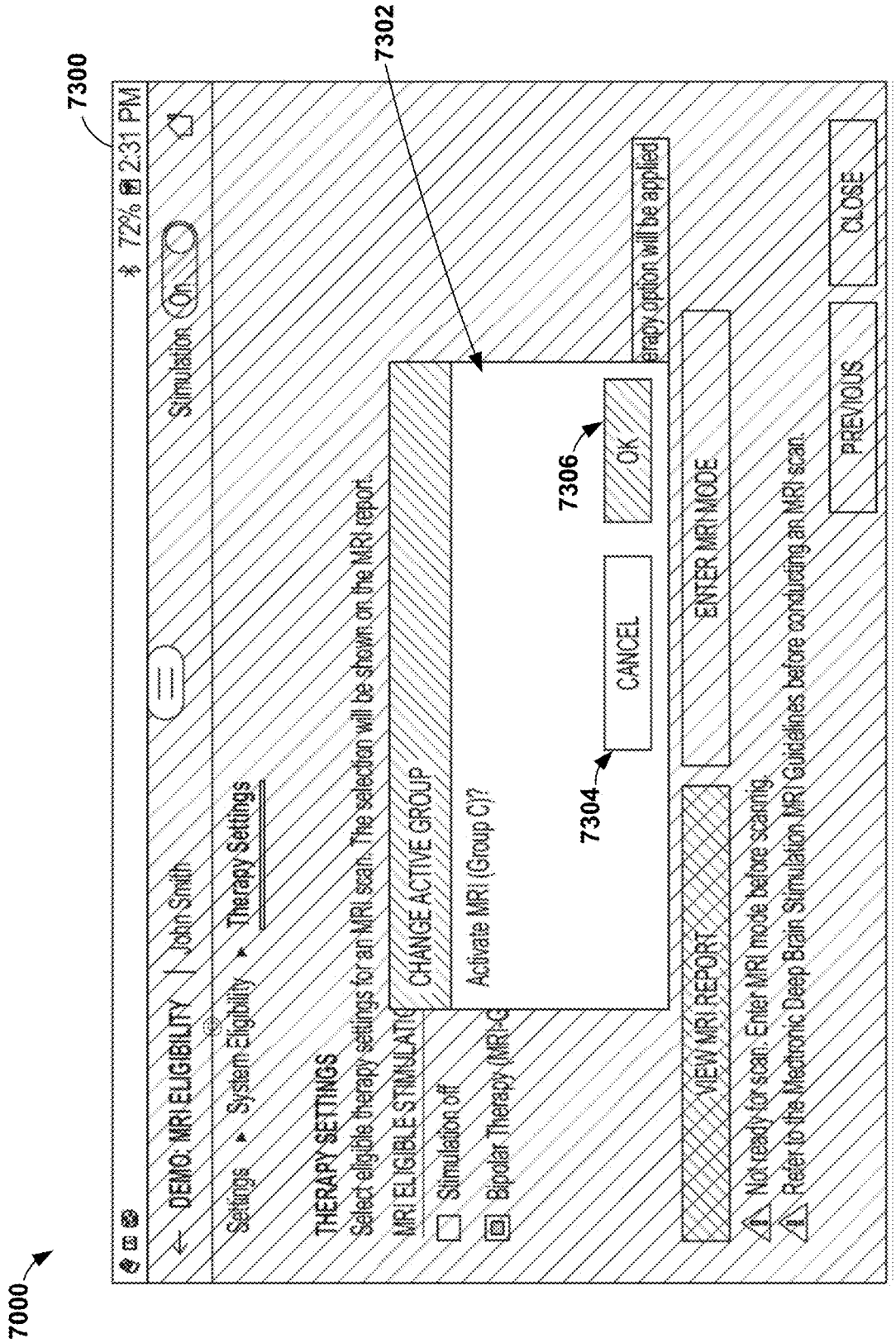

7000
7300
7302
7304
7306
DEMO: MRI ELIGIBILITY
John Smith
72% 2:31 PM
Stimulation On
Settings
System Eligibility
Therapy Settings
THERAPY SETTINGS
Select eligible therapy settings for an MRI scan. The selection will be shown on the MRI report.
MRI ELIGIBLE STIMULATI
CHANGE ACTIVE GROUP
Stimulation off
Bipolar Therapy (MRI-C
Activate MRI (Group C)?
CANCEL
OK
therapy option will be applied
ENTER MRI MODE
VIEW MRI REPORT
Not ready for scan. Enter MRI mode before scanning.
Refer to the Medtronic Deep Brain Stimulation MRI Guidelines before conducting an MRI scan.
PREVIOUS
CLOSE

FIG. 73

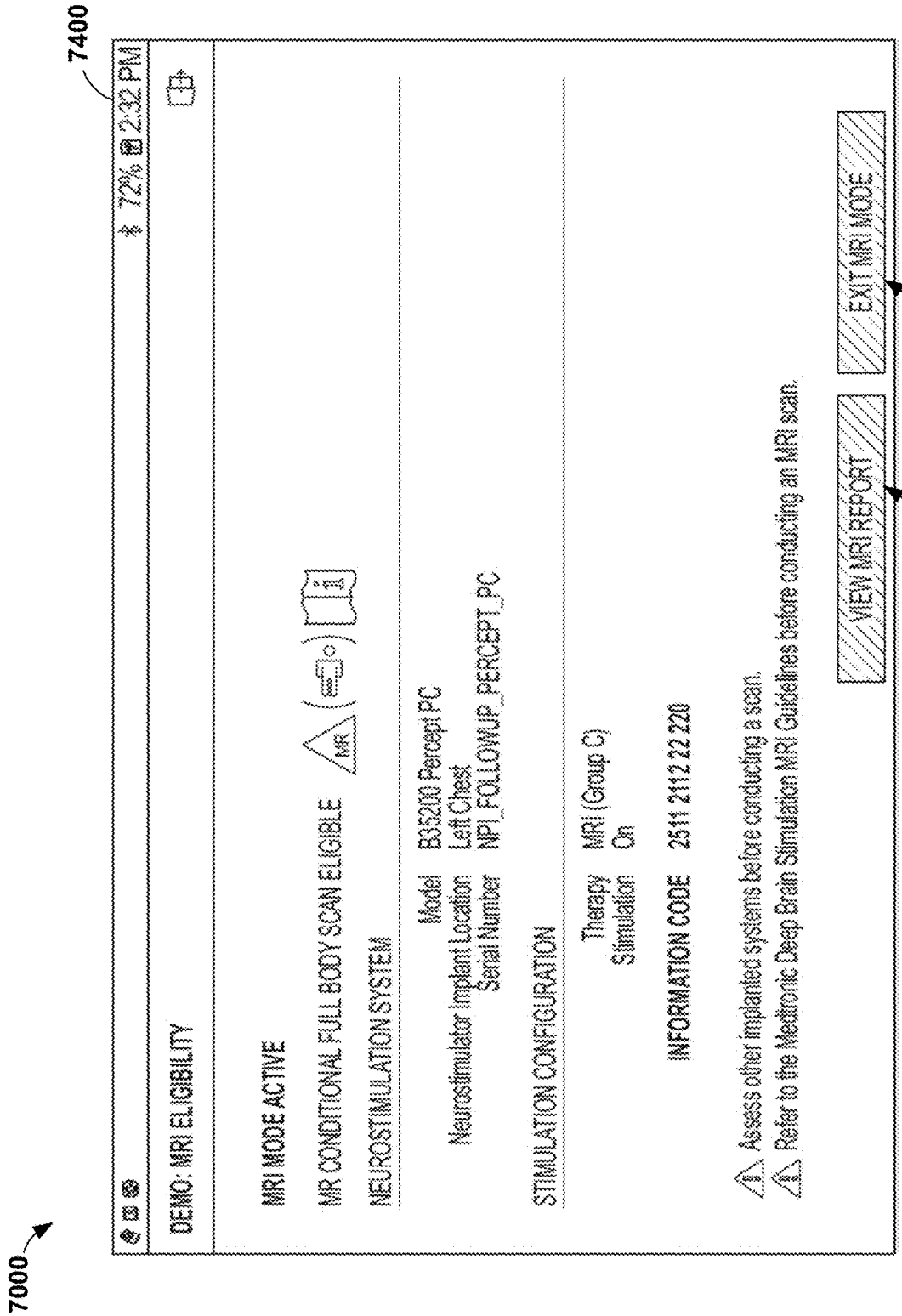

7000
7400
72% 2:32 PM
DEMO: MRI ELIGIBILITY
MRI MODE ACTIVE
MR CONDITIONAL FULL BODY SCAN ELIGIBLE
NEUROSTIMULATION SYSTEM
Model B35200 Percept PC
Neurostimulator Implant Location Left Chest
Serial Number NPI_FOLLOWUP_PERCEPT_PC
STIMULATION CONFIGURATION
Therapy MRI (Group C)
Stimulation On
INFORMATION CODE 2511 2112 22 220
Assess other implanted systems before conducting a scan.
Refer to the Medtronic Deep Brain Stimulation MRI Guidelines before conducting an MRI scan.
VIEW MRI REPORT
EXIT MRI MODE
7402
7404

FIG. 74

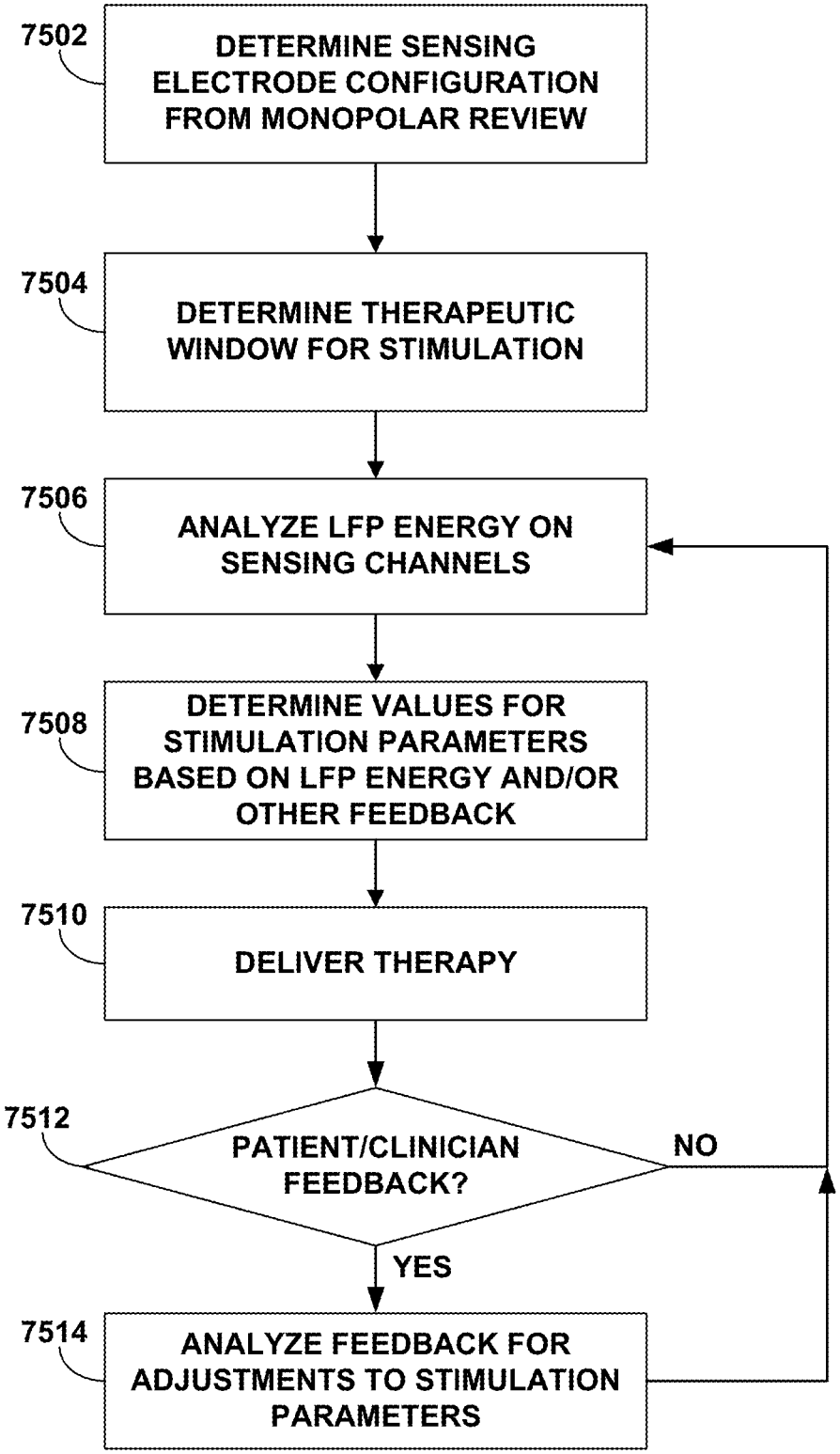

7502
DETERMINE SENSING ELECTRODE CONFIGURATION FROM MONOPOLAR REVIEW
7504
DETERMINE THERAPEUTIC WINDOW FOR STIMULATION
7506
ANALYZE LFP ENERGY ON SENSING CHANNELS
7508
DETERMINE VALUES FOR STIMULATION PARAMETERS BASED ON LFP ENERGY AND/OR OTHER FEEDBACK
7510
DELIVER THERAPY
7512
PATIENT/CLINICIAN FEEDBACK?
NO
YES
7514
ANALYZE FEEDBACK FOR ADJUSTMENTS TO STIMULATION PARAMETERS

FIG. 75

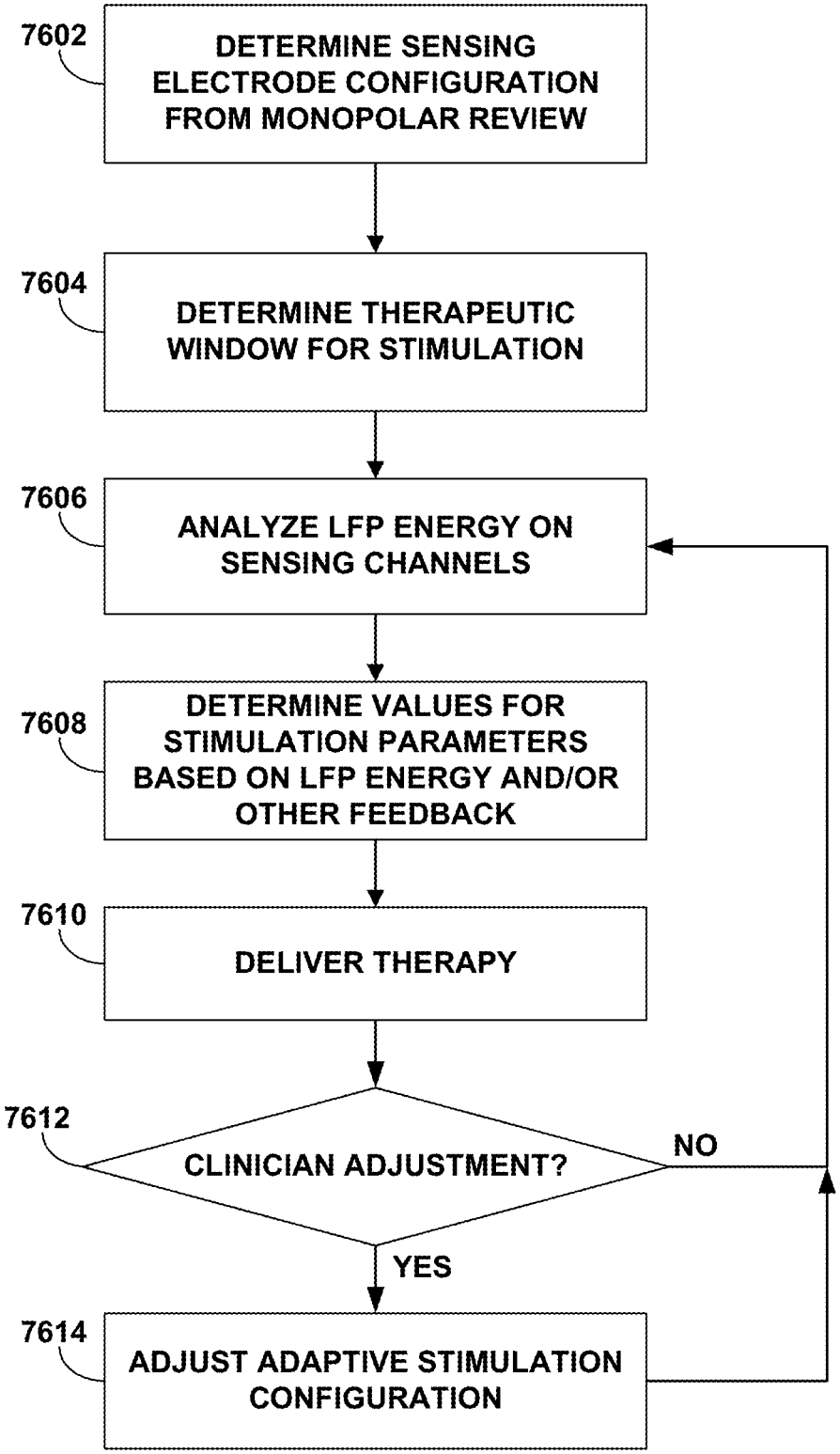

7602
DETERMINE SENSING ELECTRODE CONFIGURATION FROM MONOPOLAR REVIEW
7604
DETERMINE THERAPEUTIC WINDOW FOR STIMULATION
7606
ANALYZE LFP ENERGY ON SENSING CHANNELS
7608
DETERMINE VALUES FOR STIMULATION PARAMETERS BASED ON LFP ENERGY AND/OR OTHER FEEDBACK
7610
DELIVER THERAPY
7612
CLINICIAN ADJUSTMENT?
NO
YES
7614
ADJUST ADAPTIVE STIMULATION CONFIGURATION

FIG. 76

BRAIN STIMULATION AND SENSING

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/955,861, filed Dec. 31, 2019 and entitled "BRAIN STIMULATION AND SENSING," the entire contents of which are incorporated by reference herein.

TECHNICAL FIELD

[0002] This disclosure generally relates to electrical stimulation therapy.

BACKGROUND

[0003] Medical devices may be external or implanted, and may be used to deliver electrical stimulation therapy to various tissue sites of a patient to treat a variety of symptoms or conditions such as chronic pain, tremor, Parkinson's disease, other movement disorders, epilepsy, urinary or fecal incontinence, sexual dysfunction, obesity, or gastroparesis. A medical device may deliver electrical stimulation therapy via one or more leads that include electrodes located proximate to target locations associated with the brain, the spinal cord, pelvic nerves, peripheral nerves, or the gastrointestinal tract of a patient. Hence, electrical stimulation may be used in different therapeutic applications, such as deep brain stimulation (DBS), spinal cord stimulation (SCS), pelvic stimulation, gastric stimulation, or peripheral nerve field stimulation (PNFS).

[0004] A clinician may select values for a number of programmable parameters in order to define the electrical stimulation therapy to be delivered by the implantable stimulator to a patient. For example, the clinician may select one or more electrodes for delivery of the stimulation, a polarity of each selected electrode, a voltage or current amplitude, a pulse width, and a pulse frequency as stimulation parameters. A set of parameters, such as a set including electrode combination, electrode polarity, voltage or current amplitude, pulse width and pulse rate, may be referred to as a program in the sense that they define the electrical stimulation therapy to be delivered to the patient.

SUMMARY

[0005] In general, the disclosure describes devices, systems, and techniques for managing DBS therapy, which may include monitoring brain signals, stimulation parameter values, patient events, or other aspects related to the patient and the DBS therapy. For example, a programming device may be configured to present a user interface configured to present information related to DBS therapy and/or brain signal monitoring. The system may include a medical device (e.g., an implantable medical device) configured to sense physiological signals such as electrical signals originating in the patient's brain. The system may employ aspects of these signals for presenting information to the user and/or guiding the user to select various parameters for sensing and/or delivering stimulation.

[0006] For example, an external device (e.g., an external programmer) may include a user interface that is configured to receive user input selecting one or more electrode configurations for delivering stimulation and/or sensing brain signals. The system may suggest and/or receive user input defining one or more thresholds that determine therapy parameter values or request patient data. In some examples, the user interface may be configured to present stored and/or real-time brain signal data alone or together with one or more stimulation parameter values defining stimulation delivered when the brain signal data is sensed. In some examples, the external programming device may control a medical device to perform one or more signal tests for one or more electrode combinations (e.g., one or more signal pathways) of an implanted lead. The programming devices, user interfaces, and techniques described herein may thus enable a user (e.g., a clinician or patient) to manage one or more aspects of DBS therapy.

[0007] In one example, a method includes obtaining, by processing circuitry, brain signal information for at least one electrode combination of a plurality of electrode combinations of one or more electrical leads; determining, by the processing circuitry and based on the brain signal information, a respective frequency for the at least one electrode combination; outputting, for display, a plurality of selectable lead icons, wherein each selectable lead icon of the plurality of selectable lead icons represents a different electrode combination of the plurality of electrode combinations; outputting, for display, the respective frequency determined for the at least one electrode combination in association with the respective selectable lead icon associated with the at least one electrode combination; receiving user input selecting one selectable lead icon of the plurality of selectable lead icons; and responsive to receiving the user input, selecting, by the processing circuitry and for subsequent brain signal sensing, a sense electrode combination associated with the one selectable lead icon selected by the user input.

[0008] In another example, a method includes obtaining, by processing circuitry, a brain signal representative of electrical activity of a brain of a patient; controlling, by the processing circuitry, a medical device to deliver electrical stimulation defined by at least a first value of a stimulation parameter; adjusting, by the processing circuitry, the first value of the stimulation parameter to a second value of the stimulation parameter at which a patient condition is identified; and determining, by the processing circuitry, a threshold value for the brain signal associated with the patient condition, wherein the medical device is configured to limit automatic adjustment of the stimulation parameter to the second value associated with the threshold value.

[0009] In another example, a method includes obtaining, by processing circuitry, a brain signal representative of electrical activity of a brain of a patient; obtaining, by the processing circuitry, one or more values of a stimulation parameter that at least partially defines electrical stimulation deliverable to a portion of the brain of the patient; and outputting, for display by a user interface, a graph comprising a first trace of the brain signal for a period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

[0010] In another example, a method includes obtaining, by processing circuitry and from a first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time; obtaining, by the processing circuitry, stimulation parameter information comprising one or more values of a stimulation parameter that at least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and outputting, for display by a user interface, a graph comprising a first trace of the brain signal information for the period

of time and a second trace of the one or more values of the stimulation parameter for the period of time.

[0011] In another example, a method includes obtaining, by processing circuitry, brain signal information representative of electrical activity of a brain of a patient over a period of time; determining, by the processing circuitry, a first amount of time an amplitude of the brain signal information was greater than an upper threshold during the period of time; determining, by the processing circuitry, a second amount of time the amplitude of the brain signal information was less than a lower threshold during the period of time; determining, by the processing circuitry, a third amount of time the amplitude of the brain signal information was between the upper threshold and the lower threshold during the period of time; and outputting, for display via a user interface, a representation of the first amount of time, the second amount of time, and the third amount of time.

[0012] In another example, a method includes receiving, by processing circuitry, an indication of an event at a time; responsive to receiving the indication of the event, storing spectral information for a brain signal recorded at the time; and outputting, for display by a user interface, a graph indicating the spectral information for the brain signal recorded at the time.

[0013] The details of one or more examples of the techniques of this disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the techniques will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0014] FIG. **1** is a conceptual diagram illustrating an example system that includes an implantable medical device (IMD) configured to deliver DBS to a patient according to an example of the techniques of the disclosure.

[0015] FIG. **2** is a block diagram of the example IMD of FIG. **1** for delivering DBS therapy according to an example of the techniques of the disclosure.

[0016] FIG. **3** is a block diagram of the external programmer of FIG. **1** for controlling delivery of DBS therapy according to an example of the techniques of the disclosure.

[0017] FIG. **4** is a conceptual diagram illustrating an example home screen for navigating within a user interface.

[0018] FIGS. **5** and **6** are conceptual diagrams illustrating example setup screens for managing electrode configurations.

[0019] FIG. **7** is a flowchart illustrating an example technique for running a signal test that evaluates one or more aspects of an electrode configuration.

[0020] FIGS. **8** and **9** are conceptual diagrams illustrating example screens illustrating information associated with stimulation effects for a patient.

[0021] FIG. **10** is a conceptual diagram illustrating an example screen for adjusting a frequency band for an electrode configuration.

[0022] FIG. **11** is a conceptual diagram illustrating an example screen for setting various sensing parameters for an electrode configuration.

[0023] FIG. **12** is a conceptual diagram illustrating an example screen for selecting a type of adaptive DBS mode.

[0024] FIGS. **13-20** are conceptual diagrams illustrating example screens for capturing one or more thresholds associated with adaptive DBS therapy.

[0025] FIG. **21** is a flowchart illustrating an example technique for setting one or more thresholds associated with adaptive DBS therapy.

[0026] FIG. **22** is a conceptual diagram illustrating an example screens summarizing parameters selected for adaptive DBS therapy.

[0027] FIGS. **23** and **24** are conceptual diagrams illustrating example screens for manually adjusting one or more thresholds associated with adaptive DBS therapy.

[0028] FIGS. **25-30** are conceptual diagrams illustrating example screens for displaying sensed brain signals with one or more stimulation parameters defining delivered DBS therapy.

[0029] FIG. **31** is a flowchart illustrating an example technique for displaying sensed brain signals with one or more stimulation parameters defining delivered DBS therapy.

[0030] FIGS. **32** and **33** are conceptual diagrams illustrating example screens for adjusting transitions between upper and lower stimulation parameter limits.

[0031] FIG. **34** is a conceptual diagram illustrating an example home screen for navigating to view stored patient event data.

[0032] FIGS. **35-42** are conceptual diagrams illustrating example screens for displaying patient event data arranged by user selectable times.

[0033] FIGS. **43-47** are conceptual diagrams illustrating example screens for displaying brain signal graphs for respective patient events.

[0034] FIG. **48** is a flowchart illustrating an example technique for generating and displaying brain signal graphs for respective patient events.

[0035] FIG. **49** is a conceptual diagram illustrating an example screen for displaying amounts of time a brain signal characteristic is within a respective range of brain signal values.

[0036] FIGS. **50-55** are conceptual diagrams illustrating example screens for displaying a graph of brain signal characteristics and stimulation parameter values from DBS therapy over time.

[0037] FIG. **56** is a flowchart illustrating an example technique for generating and displaying a graph of brain signal characteristics and stimulation parameter values from DBS therapy over time.

[0038] FIG. **57** is a conceptual diagram illustrating an example screen for displaying an amount of time different types of DBS therapy were delivered for respective dates.

[0039] FIGS. **58** and **59** are conceptual diagrams illustrating example screens for displaying graphs of brain signal power for respective electrode combinations of a lead.

[0040] FIGS. **60-69** are conceptual diagrams illustrating example screens of a user interface associated with entering an MRI mode for a medical device.

[0041] FIGS. **70-74** are conceptual diagrams illustrating example screens of a user interface associated with entering an MM mode for a medical device.

[0042] FIG. **75** is a flowchart illustrating an example technique for managing the sensing of brain signals.

[0043] FIG. **76** is a flowchart illustrating an example technique for setting up and managing adaptive stimulation using brain signals.

DETAILED DESCRIPTION

[0044] A patient may suffer from one or more symptoms treatable by electrical stimulation therapy. For example, a patient may suffer from brain disorder such as Parkinson's disease, Alzheimer's disease, or another type of movement disorder. Deep brain stimulation (DBS) may be an effective treatment to reduce the symptoms associated with such disorders. However, it may be time consuming for a clinician to manually determine appropriate stimulation parameters that define effective electrical stimulation therapy. Moreover, DBS is typically delivered continuously in an open loop fashion for the patient. Not only does this open loop delivery consume more battery power due to stimulation being delivered when not needed by the patient, but the system is not able to adjust stimulation parameters to provide more targeted therapy as the condition of the patient changes over time or under certain conditions. In addition, it can be challenging for clinicians to identify patient events and conditions and what types of adjustments could be made to improve therapy over time.

[0045] As described herein, various devices, systems, and techniques enable management of DBS therapy and/or brain sensing for a patient. For example, systems described herein may be configured to sense and record brain signals (e.g., electroencephalogram (EEG signals), local field potentials (LFP signals), or other brain signals) associated with brain disorders. The system may identify appropriate frequencies for different electrode combinations and/or suggest an electrode combination for sensing. The system may also display the recorded brain signals or aspects thereof for review by a user such as a clinician. In some examples, the system may operate in an adaptive DBS mode in which the system adjusts the value of one or more stimulation parameters in order to maintain the brain signals above or below one or more respective thresholds. The system may receive user input specifying or adjusting any of these thresholds. In addition, the system may employ a setup mode in which the clinician can capture brain signal thresholds that correspond to respective stimulation parameter values. In some examples, the system may be configured to record and store brain signal information in response to a user identified event and/or a system identified event, where the system can later present information regarding the brain signal to enable a clinician to view the brain signal associated with the event that occurred.

[0046] These various features may provide advantages over other systems and improve system functionality and patient outcomes. For example, the system may capture brain signals from multiple different electrode combinations and suggest an electrode combination to use for brain signal sensing, which reduces clinician trial and error during patient setup. The system may also guide a clinician through setup of one or more thresholds employed to provide adaptive DBS therapy and enable fine adjustments to these thresholds. This guide may reduce clinician time and improve therapeutic results for the patient by increasing therapeutic stimulation efficacy and reducing side effects. The system may also correlate patient condition and events with sensed brain signals and display such information for clinician review. The clinician can then identify brain signals sensed during a specific patient event, and stimulation status during such events, to monitor stimulation efficacy and adjust stimulation over time to reduce patient symptoms.

[0047] FIG. **1** is a conceptual diagram illustrating an example system **100** that includes an implantable medical device (IMD) **106** configured to deliver adaptive deep brain stimulation to a patient **112**. DBS may be adaptive in the sense that IMD **106** may adjust, increase, or decrease the magnitude of one or more stimulation parameters of the DBS in response to changes in patient activity or movement, a severity of one or more symptoms of a disease of the patient, a presence of one or more side effects due to the DBS, or one or more sensed signals of the patient, etc. For example, one or more sensed signals of the patient may be used as a control signal such that the IMD **106** correlates the magnitude of the one or more parameters of the electrical stimulation to the magnitude of the one or more sensed signals. According to the techniques of the disclosure, system **100**, via IMD **106**, delivers electrical stimulation therapy having one or more parameters, such as voltage or current amplitude, adjusted in response to a signal deviating from a range defined by a homeostatic window (e.g., a window defined by one or more thresholds for a brain signal, such as a lower threshold and upper threshold).

[0048] In other examples, the system delivers electrical stimulation therapy having the one or more parameters, such as voltage or current amplitude, adjusted in response to multiple signals, each signal deviating from a range defined by a respective homeostatic window. For example, the system may sense a first neurological signal, such as a signal within a Beta frequency band of the brain **120** of patient **112** within a first respective homeostatic window and a second neurological signal, such as a signal within a Gamma frequency band of the brain **120** of patient **112** within a second respective homeostatic window. In one example system, IMD **16** dynamically selects one of the first signal or the second signal for controlling adjustment of the one or more parameters based on a determination of which of the first signal or second signal most accurately corresponds to the severity of one or more symptoms of the patient. In another example system, IMD **106** adjusts the one or more parameters based on a ratio of the first signal to the second signal. In some examples, amplitudes of one or more frequencies in the Gamma frequency band increase with greater stimulation intensity such that higher Gamma frequency amplitudes may be associated with side effects. Conversely, amplitudes of one or more frequencies in the Beta frequency band decrease with greater stimulation intensity such that lower Gamma frequency amplitudes may be associated with side effects (e.g., dyskinesia).

[0049] In some examples, the medication taken by patient **112** is a medication for controlling one or more symptoms of Parkinson's disease, such as tremor or rigidity due to Parkinson's disease. Such medications include extended release forms of dopamine agonists, regular forms of dopamine agonists, controlled release forms of carbidopa/levodopa (CD/LD), regular forms of CD/LD, entacapone, rasagiline, selegiline, and amantadine. Typically, to set the upper threshold and lower threshold of the homeostatic window, the patient has been off medication, i.e., the upper and lower thresholds are set when the patient is not taking medication selected to reduce the symptoms. The patient may be considered to be not taking the medication when the patient, prior to the time the upper bound is set, has not taken the medication for at least approximately 72 hours for extended release forms of dopamine agonists, the patient has not taken the medication for at least approximately 24 hours for

regular forms of dopamine agonists and controlled release forms of CD/LD, and the patient has not taken the medication for at least approximately 12 hours for regular forms of CD/LD, entacapone, rasagiline, selegiline, and amantadine. If only stimulation is suppressing brain signals (e.g., LFP signals), then the system can measure these brain signals for various values of stimulation parameters without outside inputs. Once the upper threshold and lower threshold is established, the system can identify when medication wears off because the brain signals will cross the lower or upper threshold. In response to identifying the brain signal crossing a threshold, the system may turn on electrical stimulation to bring back brain signal amplitudes back between the lower threshold and the upper threshold. Programmer **104** may enable the user to initially set the lower threshold and the upper threshold and make adjustments over time. Programmer **104** may also determine and display information regarding the amount of time stimulation amplitude is above, below, or between the thresholds.

[0050] As described herein, "reducing" or "suppressing" the symptoms of the patient refer to alleviating, in whole or in part, the severity of one or more symptoms of the patient. In one example, a clinician makes a determination of the severity of one or more symptoms of Parkinson's disease of patient **112** with reference to the Unified Parkinson's Disease Rating Scale (UPDRS) or the Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS). A discussion of the application of the MDS-UPDRS is provided by Movement Disorder Society-Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Scale Presentation and Clinimetric Testing Results, C. Goetz et al, Movement Disorders, Vol. 23, No. 15, pp. 2129-2170 (2008), the content of which is incorporated herein in its entirety.

[0051] As described herein, a clinician can determine the upper threshold of the homeostatic window while the patient is not taking medication, and while, via IMD **106**, electrical stimulation therapy is delivered to the brain **120** of patient **112**. In one example, a clinician determines the point at which increasing the magnitude of one or more parameters defining the electrical stimulation therapy, such as voltage amplitude or current amplitude, begins to cause one or more side effects for the patient **112**. For example, the clinician may gradually increase the magnitude of one or more parameters defining the electrical stimulation therapy and determine the point at which further increase to the magnitude of one or more parameters defining the electrical stimulation therapy causes a perceptible side effect for patient **112**. As described herein, IMD **106** may sense LFPs during this process and display the LFP signal and/or LFP signal magnitude that may correspond to the respective thresholds.

[0052] As also described above, a clinician determines the lower threshold while the patient is off medication and while, via IMD **106**, electrical stimulation therapy is delivered to the brain **120** of patient **112**. In one example, a clinician determines the point at which decreasing the magnitude of one or more parameters defining the electrical stimulation therapy causes break-through of one or more symptoms of the patient **112**. This break-through of symptoms may refer to re-emergence of at least some symptoms that were substantially suppressed up to the point of re-emergence due to the decrease in magnitude of the one or more electrical stimulation therapy parameters. For example, the clinician may gradually decrease the magnitude of one or more parameters defining the electrical stimulation therapy and determine the point at which the symptoms of Parkinson's disease in patient **112** emerge, as measured by sudden increase with respect to tremor or rigidity, in the score of patient **112** under the UPDRS or MDS-UPDRS. In another example, the clinician measures a physiological parameter of patient **112** correlated to one or more symptoms of the disease of patient **112** (e.g., wrist flexion of patient **112**) and determines the point at which further decrease to the magnitude of one or more parameters defining the electrical stimulation therapy causes a sudden increase in the one or more symptoms of the disease of patient **112** (e.g., onset of lack of wrist flexion of patient **112**).

[0053] At the magnitude of one or more parameters defining the electrical stimulation therapy at which further decrease to the magnitude of one or more parameters defining the electrical stimulation therapy causes a sudden increase in the one or more symptoms of the disease of patient **112**, the clinician measures the magnitude of the signal of the patient **112** and sets this magnitude as the lower threshold of the homeostatic window. In some examples, the clinician may select a lower threshold of the homeostatic window to be a predetermined amount, e.g., 5% or 10%, higher than the magnitude at which the symptoms of the patient **112** first emerge during decrease in the magnitude of one or more electrical stimulation parameters to prevent emergence of the symptoms of the patient **112** during subsequent use.

[0054] In another example, the clinician sets the lower threshold by first ensuring that the patient is off medication for the one or more symptoms. In this example, the clinician delivers electrical stimulation having a value for the one or more parameters approximately equal to the upper threshold of the therapeutic window. In some examples, the clinician delivers electrical stimulation having a value for the one or more parameters slightly below the magnitude which induces side effects in the patient **112**. Typically, this causes greater reduction of the one or more symptoms of the disease of the patient **112**, and therefore greater reduction of the signal. At this magnitude of the one or more parameters, the clinician measures the magnitude of the signal of the patient **112** and sets, via external programmer **104**, this magnitude as the lower threshold of the homeostatic window. In some examples, the clinician may select a value for the lower threshold of the homeostatic window to be a predetermined amount, e.g., 5% or 10%, higher than the magnitude at which the symptoms of the patient **112** emerge to prevent emergence of the symptoms of the patient **112** during subsequent use.

[0055] Additionally, in one example of the techniques of the disclosure, the system monitors a signal of the patient. In one example, the signal is a neurological signal of a patient, such as a signal within a Beta frequency band or a Gamma frequency band of the brain of the patient. In yet a further example, the signal is a signal indicative of a physiological parameter of the patient, such as a severity of a symptom of the patient, a posture of the patient, a respiratory function of the patient, or an activity level of the patient. For example, the monitored signal may be a power of the respective Beta frequency band and/or Gamma frequency band.

[0056] The system, via IMD **106**, delivers electrical stimulation to the patient, wherein one or more parameters defining the electrical stimulation are proportional to the magnitude of the monitored signal.

[0057] System **100** may be configured to treat a patient condition, such as a movement disorder, neurodegenerative impairment, a mood disorder, or a seizure disorder of patient **112**. Patient **112** ordinarily is a human patient. In some cases, however, therapy system **100** may be applied to other mammalian or non-mammalian, non-human patients. While movement disorders and neurodegenerative impairment are primarily referred to herein, in other examples, therapy system **100** may provide therapy to manage symptoms of other patient conditions, such as, but not limited to, seizure disorders (e.g., epilepsy) or mood (or psychological) disorders (e.g., major depressive disorder (MDD), bipolar disorder, anxiety disorders, post-traumatic stress disorder, dysthymic disorder, and obsessive-compulsive disorder (OCD)). At least some of these disorders may be manifested in one or more patient movement behaviors. As described herein, a movement disorder or other neurodegenerative impairment may include symptoms such as, for example, muscle control impairment, motion impairment or other movement problems, such as rigidity, spasticity, bradykinesia, rhythmic hyperkinesia, nonrhythmic hyperkinesia, and akinesia. In some cases, the movement disorder may be a symptom of Parkinson's disease. However, the movement disorder may be attributable to other patient conditions.

[0058] Example therapy system **100** includes medical device programmer **104**, implantable medical device (IMD) **106**, lead extension **110**, and leads **114**A and **114**B with respective sets of electrodes **116**, **118**. In the example shown in FIG. **1**, electrodes **116**, **118** of leads **114**A, **114**B are positioned to deliver electrical stimulation to a tissue site within brain **120**, such as a deep brain site under the dura mater of brain **120** of patient **112**. In some examples, delivery of stimulation to one or more regions of brain **120**, such as the subthalamic nucleus, globus pallidus or thalamus, may be an effective treatment to manage movement disorders, such as Parkinson's disease. Some or all of electrodes **116**, **118** also may be positioned to sense neurological brain signals within brain **120** of patient **112**. In some examples, some of electrodes **116**, **118** may be configured to sense neurological brain signals and others of electrodes **116**, **118** may be configured to deliver adaptive electrical stimulation to brain **120**. In other examples, all of electrodes **116**, **118** are configured to both sense neurological brain signals and deliver adaptive electrical stimulation to brain **120**.

[0059] IMD **106** includes a therapy module (e.g., which may include processing circuitry, signal generation circuitry or other electrical circuitry configured to perform the functions attributed to IMD **106**) that includes a stimulation generator configured to generate and deliver electrical stimulation therapy to patient **112** via a subset of electrodes **116**, **118** of leads **114**A and **114**B, respectively. The subset of electrodes **116**, **118** that are used to deliver electrical stimulation to patient **112**, and, in some cases, the polarity of the subset of electrodes **116**, **118**, may be referred to as a stimulation electrode combination. As described in further detail below, the stimulation electrode combination can be selected for a particular patient **112** and target tissue site (e.g., selected based on the patient condition). The group of electrodes **116**, **118** includes at least one electrode and can include a plurality of electrodes. In some examples, the plurality of electrodes **116** and/or **118** may have a complex electrode geometry such that two or more electrodes are located at different positions around the perimeter of the respective lead.

[0060] In some examples, the neurological signals sensed within brain **120** may reflect changes in electrical current produced by the sum of electrical potential differences across brain tissue. Examples of neurological brain signals include, but are not limited to, electrical signals generated from local field potentials (LFP) sensed within one or more regions of brain **120**, such as an electroencephalogram (EEG) signal, or an electrocorticogram (ECoG) signal. Local field potentials, however, may include a broader genus of electrical signals within brain **120** of patient **112**.

[0061] In some examples, the neurological brain signals that are used to select a stimulation electrode combination may be sensed within the same region of brain **120** as the target tissue site for the electrical stimulation. As previously indicated, these tissue sites may include tissue sites within anatomical structures such as the thalamus, subthalamic nucleus or globus pallidus of brain **120**, as well as other target tissue sites. The specific target tissue sites and/or regions within brain **120** may be selected based on the patient condition. Thus, in some examples, the electrodes used for delivering electrical stimulation may be different than the electrodes used for sensing neurological brain signals. In other examples, the same electrodes may be used to deliver electrical stimulation and sense brain signals. However, this configuration would require the system to switch between stimulation generation and sensing circuitry and may reduce the time the system can sense brain signals.

[0062] Electrical stimulation generated by IMD **106** may be configured to manage a variety of disorders and conditions. In some examples, the stimulation generator of IMD **106** is configured to generate and deliver electrical stimulation pulses to patient **112** via electrodes of a selected stimulation electrode combination. However, in other examples, the stimulation generator of IMD **106** may be configured to generate and deliver a continuous wave signal, e.g., a sine wave or triangle wave. In either case, a stimulation generator within IMD **106** may generate the electrical stimulation therapy for DBS according to a therapy program that is selected at that given time in therapy. In examples in which IMD **106** delivers electrical stimulation in the form of stimulation pulses, a therapy program may include a set of therapy parameter values (e.g., stimulation parameters), such as a stimulation electrode combination for delivering stimulation to patient **112**, pulse frequency, pulse width, and a current or voltage amplitude of the pulses. As previously indicated, the electrode combination may indicate the specific electrodes **116**, **118** that are selected to deliver stimulation signals to tissue of patient **112** and the respective polarities of the selected electrodes.

[0063] IMD **106** may be implanted within a subcutaneous pocket above the clavicle, or, alternatively, on or within cranium **122** or at any other suitable site within patient **112**. Generally, IMD **106** is constructed of a biocompatible material that resists corrosion and degradation from bodily fluids. IMD **106** may comprise a hermetic housing to substantially enclose components, such as a processor, therapy module, and memory.

[0064] As shown in FIG. **1**, implanted lead extension **110** is coupled to IMD **106** via connector **108** (also referred to as

a connector block or a header of IMD **106**). In the example of FIG. **1**, lead extension **110** traverses from the implant site of IMD **106** and along the neck of patient **112** to cranium **122** of patient **112** to access brain **120**. In the example shown in FIG. **1**, leads **114**A and **114**B (collectively "leads **114**") are implanted within the right and left hemispheres, respectively, of patient **112** in order deliver electrical stimulation to one or more regions of brain **120**, which may be selected based on the patient condition or disorder controlled by therapy system **100**. The specific target tissue site and the stimulation electrodes used to deliver stimulation to the target tissue site, however, may be selected, e.g., according to the identified patient behaviors and/or other sensed patient parameters. Other lead **114** and IMD **106** implant sites are contemplated. For example, IMD **106** may be implanted on or within cranium **122**, in some examples. Or leads **114** may be implanted within the same hemisphere or IMD **106** may be coupled to a single lead implanted in a single hemisphere.

[0065] Existing lead sets include axial leads carrying ring electrodes disposed at different axial positions and so-called "paddle" leads carrying planar arrays of electrodes. Selection of electrode combinations within an axial lead, a paddle lead, or among two or more different leads presents a challenge to the clinician. In some examples, more complex lead array geometries may be used.

[0066] Although leads **114** are shown in FIG. **1** as being coupled to a common lead extension **110**, in other examples, leads **114** may be coupled to IMD **106** via separate lead extensions or directly to connector **108**. Leads **114** may be positioned to deliver electrical stimulation to one or more target tissue sites within brain **120** to manage patient symptoms associated with a movement disorder of patient **112**. Leads **114** may be implanted to position electrodes **116**, **118** at desired locations of brain **120** through respective holes in cranium **122**. Leads **114** may be placed at any location within brain **120** such that electrodes **116**, **118** are capable of providing electrical stimulation to target tissue sites within brain **120** during treatment. For example, electrodes **116**, **118** may be surgically implanted under the dura mater of brain **120** or within the cerebral cortex of brain **120** via a burr hole in cranium **122** of patient **112**, and electrically coupled to IMD **106** via one or more leads **114**.

[0067] In the example shown in FIG. **1**, electrodes **116**, **118** of leads **114** are shown as ring electrodes. Ring electrodes may be used in DBS applications because they are relatively simple to program and are capable of delivering an electrical field to any tissue adjacent to electrodes **116**, **118**. In other examples, electrodes **116**, **118** may have different configurations. For example, in some examples, at least some of the electrodes **116**, **118** of leads **114** may have a complex electrode array geometry that is capable of producing shaped electrical fields. The complex electrode array geometry may include multiple electrodes (e.g., partial ring or segmented electrodes) around the outer perimeter of each lead **114**, rather than one ring electrode. In this manner, electrical stimulation may be directed in a specific direction from leads **114** to enhance therapy efficacy and reduce possible adverse side effects from stimulating a large volume of tissue. In some examples, a housing of IMD **106** may include one or more stimulation and/or sensing electrodes. In alternative examples, leads **114** may have shapes other than elongated cylinders as shown in FIG. **1**. For example, leads **114** may be paddle leads, spherical leads, bendable leads, or any other type of shape effective in treating patient **112** and/or minimizing invasiveness of leads **114**.

[0068] In the example shown in FIG. **1**, IMD **106** includes a memory to store a plurality of therapy programs that each define a set of therapy parameter values. In some examples, IMD **106** may select a therapy program from the memory based on various parameters, such as sensed patient parameters and the identified patient behaviors. IMD **106** may generate electrical stimulation based on the selected therapy program to manage the patient symptoms associated with a movement disorder.

[0069] External programmer **104** wirelessly communicates with IMD **106** as needed to provide or retrieve therapy information. Programmer **104** is an external computing device that the user, e.g., a clinician and/or patient **112**, may use to communicate with IMD **106**. For example, programmer **104** may be a clinician programmer that the clinician uses to communicate with IMD **106** and program one or more therapy programs for IMD **106**. Alternatively, programmer **104** may be a patient programmer that allows patient **112** to select programs and/or view and modify therapy parameters. The clinician programmer may include more programming features than the patient programmer. In other words, more complex or sensitive tasks may only be allowed by the clinician programmer to prevent an untrained patient from making undesirable changes to IMD **106**.

[0070] When programmer **104** is configured for use by the clinician, programmer **104** may be used to transmit initial programming information to IMD **106**. This initial information may include hardware information, such as the type of leads **114** and the electrode arrangement, the position of leads **114** within brain **120**, the configuration of electrode array **116**, **118**, initial programs defining therapy parameter values, and any other information the clinician desires to program into IMD **106**. Programmer **104** may also be capable of completing functional tests (e.g., measuring the impedance of electrodes **116**, **118** of leads **114**). In addition, or as an alternative, to programmer **104**, a different external computing device may perform any of the functionality of programmer **104**. The external computing device may be a networked device and in communication with IMD **106** directly or via programmer **104**.

[0071] The clinician may also store therapy programs within IMD **106** with the aid of programmer **104**. During a programming session, the clinician may determine one or more therapy programs that may provide efficacious therapy to patient **112** to address symptoms associated with the patient condition, and, in some cases, specific to one or more different patient states, such as a sleep state, movement state or rest state. For example, the clinician may select one or more stimulation electrode combination with which stimulation is delivered to brain **120**. During the programming session, the clinician may evaluate the efficacy of the specific program being evaluated based on feedback provided by patient **112** or based on one or more physiological parameters of patient **112** (e.g., muscle activity, muscle tone, rigidity, tremor, etc.). Alternatively, identified patient behavior from video information may be used as feedback during the initial and subsequent programming sessions. Programmer **104** may assist the clinician in the creation/identification of therapy programs by providing a methodical system for identifying potentially beneficial therapy parameter values.

[0072] Programmer **104** may also be configured for use by patient **112**. When configured as a patient programmer,

programmer **104** may have limited functionality (compared to a clinician programmer) in order to prevent patient **112** from altering critical functions of IMD **106** or applications that may be detrimental to patient **112**. In this manner, programmer **104** may only allow patient **112** to adjust values for certain therapy parameters or set an available range of values for a particular therapy parameter.

[0073] Programmer **104** may also provide an indication to patient **112** when therapy is being delivered, when patient input has triggered a change in therapy or when the power source within programmer **104** or IMD **106** needs to be replaced or recharged. For example, programmer **112** may include an alert LED, may flash a message to patient **112** via a programmer display, generate an audible sound or somatosensory cue to confirm patient input was received, e.g., to indicate a patient state or to manually modify a therapy parameter.

[0074] Therapy system **100** may be implemented to provide chronic stimulation therapy to patient **112** over the course of several months or years. However, system **100** may also be employed on a trial basis to evaluate therapy before committing to full implantation. If implemented temporarily, some components of system **100** may not be implanted within patient **112**. For example, patient **112** may be fitted with an external medical device, such as a trial stimulator, rather than IMD **106**. The external medical device may be coupled to percutaneous leads or to implanted leads via a percutaneous extension. If the trial stimulator indicates DBS system **100** provides effective treatment to patient **112**, the clinician may implant a chronic stimulator within patient **112** for relatively long-term treatment.

[0075] Although IMD **104** is described as delivering electrical stimulation therapy to brain **120**, IMD **106** may be configured to direct electrical stimulation to other anatomical regions of patient **112** in other examples. In other examples, system **100** may include an implantable drug pump in addition to, or in place of, IMD **106**. Further, an IMD may provide other electrical stimulation such as spinal cord stimulation to treat a movement disorder.

[0076] According to the techniques of the disclosure, system **100** defines a homeostatic window and a therapeutic window for delivering adaptive DBS to patient **112**. System **100** may adaptively deliver electrical stimulation and adjust one or more parameters defining the electrical stimulation within a parameter range defined by upper and lower limits of the therapeutic window based on the activity of the sensed signal (e.g., LFP signal) within the homeostatic window. For example, system **100** may adjust the one or more parameters defining the electrical stimulation in response to the sensed signal falling below the lower threshold or exceeding the upper threshold of the homeostatic window, but may not adjust the one or more parameters defining the electrical stimulation such that they fall below the lower limit or exceed the upper limit of the therapeutic window.

[0077] In one example, external programmer **104** issues commands to IMD **106** causing IMD **106** to deliver electrical stimulation therapy via electrodes **116**, **118** via leads **114**. As described above, the therapeutic window defines an upper bound and a lower bound for one or more parameters defining the delivery of electrical stimulation therapy to patient **112**. For example, the one or more parameters include a current amplitude (for a current-controlled system) or a voltage amplitude (for a voltage-controlled system), a pulse rate or frequency, and a pulse width. In examples where the electrical stimulation is delivered according to a "burst" of pulses, or a series of electrical pulses defined by an "on-time" and an "off-time," the one or more parameters may further define one or more of a number of pulses per burst, an on-time, and an off-time. In one example, the therapeutic window defines an upper bound and a lower bound for one or more parameters, such as upper and lower threshold for a current amplitude of the electrical stimulation therapy (in current-controlled systems) or upper and lower threshold of a voltage amplitude of the electrical stimulation therapy (in voltage-controlled systems). While the examples herein are typically given with respect to adjusting a voltage amplitude or a current amplitude, the techniques herein may equally be applied to a homeostatic window and a therapeutic window using other parameters, such as, e.g., pulse rate or pulse width. Example implementations of the therapeutic window are provided in further detail below.

[0078] Typically, a patient programmer **104** may not have access to adjustments to any thresholds or limits for sensing or stimulation related to adaptive DBS. For example, patient programmer **104** may only enable a patient to adjust a stimulation parameter value between limits set by the clinician programmer. However, in other examples, system **100** may provide adaptive DBS by permitting a patient **112**, e.g., via a patient programmer **104**, to indirectly adjust the activation, deactivation, and magnitude of the electrical stimulation by adjusting the lower and upper threshold of the homeostatic window. In one example, the patient programmer **104** may only be enabled to adjust an upper or lower threshold a small magnitude or percentage of the clinician-set value. In another example, by adjusting one or both thresholds of the homeostatic window, patient **112** may adjust the point at which the sensed signal deviates from the homeostatic window, triggering system **100** to adjust one or more parameters of the electrical stimulation within a parameter range defined by the lower and upper threshold of the therapeutic window.

[0079] In some examples, a patient may provide feedback, e.g., via programmer **104**, to adjust one or both threshold of the homeostatic window. In another example, programmer **104** and/or IMD **106** may automatically adjust one or both threshold of the homeostatic window, as well as one or more parameters of the electrical stimulation within the parameter range defined by the lower and upper threshold of the therapeutic window. For example, IMD **106** may adjust the delivery of adaptive DBS by automatically adjusting one or more thresholds (e.g., an upper and a lower threshold in some examples) of the homeostatic window, e.g., in response to a physiological parameter sensed by one or more sensors **109** of system **100**. As a further example, programmer **104** and/or IMD **106** may automatically adjust one or more thresholds of the homeostatic window based on one or more physiological or neurological signals of patient **112** sensed by IMD **106**. For example, in response to deviations in the signal of the patient outside of the homeostatic window, system **100** (e.g., IMD **106** or programmer **104**) may automatically adjust one or more parameters defining the electrical stimulation therapy delivered to the patient in a manner that is proportional to the magnitude of the sensed signal and within the therapeutic window defining lower and upper thresholds for the one or more parameters. The adjustment to the one or more stimulation therapy param-

eters based on the deviation of the sensed signal may be proportional or inversely proportional to the magnitude of the signal.

[0080] Hence, in some examples, system **100**, via programmer **104** or IMD **106**, may adjust one or more parameters of the electrical stimulation, such as voltage or current amplitude, within the therapeutic window based on patient input that adjusts the homeostatic window, or based on one or more signals, such as sensed physiological parameters or sensed neurological signals, or a combination of two or more of the above. In particular, system **100** may adjust a parameter of the electrical stimulation, automatically and/or in response to patient input that adjusts the homeostatic window, provided the value of the electrical stimulation parameter is constrained to remain within a range specified by the upper and lower threshold of the therapeutic window. This range may be considered to include the upper and lower threshold themselves.

[0081] In some examples where system **100** adjusts multiple parameters of the electrical stimulation, system **100** may adjust at least one of a voltage amplitude or current amplitude, a stimulation frequency, a pulse width, or a selection of electrodes, and the like. In such an example, the clinician may set an order or sequence for adjustment of the parameters (e.g., adjust voltage amplitude or current amplitude, then adjust stimulation frequency, and then adjust the selection of electrodes). In other examples, system **100** may randomly select a sequence of adjustments to the multiple parameters. In either example, system **100** may adjust a value of a first parameter of the parameters of the electrical stimulation. If the signal does not exhibit a response to the adjustment of the first parameter, system **100** may adjust a value of a second parameter of the parameters of the electrical stimulation, and so on until the signal returns to within the homeostatic window.

[0082] To adaptively adjust DBS based on a neurological signal, for example, two or more electrodes **116**, **118** of IMD **106** may be configured to monitor a neurological signal (e.g., an LFP signal) of patient **112**. In some examples, at least one of electrodes **116**, **118** may be provided on a housing of IMD **106**, providing a unipolar stimulation and/or sensing configuration. In one example, the neurological signal is a signal within a Beta frequency band of brain **120** of patient **112**. For example, neurological signals within the Beta frequency band of patient **112** may correlate to one or more symptoms of Parkinson's disease in patient **112**. Generally speaking, neurological signals within the Beta frequency of patient **112** may be approximately proportional to the severity of the symptoms of patient **112**. For example, as tremor induced by Parkinson's disease increases, neurological signals within the Beta frequency of patient **112** increase (e.g., magnitude of the signal and/or spectral power). Moreover, neurological signals within the Beta frequency are considered proportional because system **100** may be configured such that an increase in signal magnitude may trigger system **100** to increase delivered stimulation therapy magnitude according to disclosed techniques. Similarly, as tremor induced by Parkinson's disease decreases, neurological signals within the Beta frequency of patient **112** decrease (e.g., magnitude of the signal and/or spectral power), and the decrease may trigger system **100** to decrease the magnitude of delivered stimulation.

[0083] In some examples, each of a sensor within IMD **106** is an accelerometer, a bonded piezoelectric crystal, a mercury switch, or a gyro. In some examples, these sensors may provide a signal that indicates a physiological parameter of the patient, which in turn varies as a function of patient activity. For example, the device may monitor a signal that indicates the heart rate, electrocardiogram (ECG) morphology, electroencephalogram (EEG) morphology, respiration rate, respiratory volume, core temperature, subcutaneous temperature, or muscular activity of the patient.

[0084] In some examples, the sensors generate a signal both as a function of patient activity and patient posture. For example, accelerometers, gyros, or magnetometers may generate signals that indicate both the activity and the posture of a patient **112**. External programmer **104** may use such information regarding posture to determine whether external programmer **104** should perform adjustments to the therapeutic window.

[0085] For example, in order to identify posture, the sensors such as accelerometers may be oriented substantially orthogonally with respect to each other. In addition to being oriented orthogonally with respect to each other, each of the sensors used to detect the posture of a patient **112** may be substantially aligned with an axis of the body of a patient **112**. When accelerometers, for example, are aligned in this manner, the magnitude and polarity of DC components of the signals generate by the accelerometers indicate the orientation of the patient relative to the Earth's gravity, e.g., the posture of a patient **112**. Further information regarding use of orthogonally aligned accelerometers to determine patient posture may be found in a commonly assigned U.S. Pat. No. 5,593,431, which issued to Todd J. Sheldon, the entire content of which is incorporated by reference herein.

[0086] Other sensors that may generate a signal that indicates the posture of a patient **112** include electrodes that generate a signal as a function of electrical activity within muscles of a patient **112**, e.g., an electromyogram (EMG) signal, or a bonded piezoelectric crystal that generates a signal as a function of contraction of muscles. Electrodes or bonded piezoelectric crystals may be implanted in the legs, buttocks, chest, abdomen, or back of a patient **112**, and coupled to one or more of external programmer **104** and IMD **106** wirelessly or via one or more leads. Alternatively, electrodes may be integrated in a housing of the IMD **106** or piezoelectric crystals may be bonded to the housing when IMD **106** is implanted in the buttocks, chest, abdomen, or back of a patient **112**. The signals generated by such sensors when implanted in these locations may vary based on the posture of a patient **112**, e.g., may vary based on whether the patient is standing, sitting, or lying down.

[0087] Further, the posture of a patient **112** may affect the thoracic impedance of the patient. Consequently, sensors may include an electrode pair, including one electrode integrated with the housing of IMDs **106** and one of electrodes **116**, **118**, that generate a signal as a function of the thoracic impedance of a patient **112**, and IMD **106** may detect the posture or posture changes of a patient **112** based on the signal. In one example (not depicted), the electrodes of the pair may be located on opposite sides of the patient's thorax. For example, the electrode pair may include electrodes located proximate to the spine of a patient for delivery of SCS therapy, and IMD **106** with an electrode integrated in its housing may be implanted in the abdomen or chest of patient **112**. As another example, IMD **106** may include electrodes implanted to detect thoracic impedance in addition to leads **114** implanted within the brain of patient **112**.

The posture or posture changes may affect the delivery of DBS or SCS therapy to patient **112** for the treatment of any type of neurological disorder, and may also be used to detect patient sleep, as described herein.

[0088] Additionally, changes of the posture of a patient **112** may cause pressure changes with the cerebrospinal fluid (CSF) of the patient. Consequently, sensors may include pressure sensors coupled to one or more intrathecal or intracerebroventricular catheters, or pressure sensors coupled to IMDs **106** wirelessly or via one of leads **114**. CSF pressure changes associated with posture changes may be particularly evident within the brain of the patient, e.g., may be particularly apparent in an intracranial pressure (ICP) waveform.

[0089] Accordingly, in some examples, instead of monitoring a neurological signal of the patient, the system **100** monitors one or more signals from sensors indicative of a magnitude of a physiological parameter of patient **112**. Upon detecting that one or more signals from sensors exceed the upper bound of the homeostatic window, the system **100** increases stimulation at a maximum ramp rate determined by the clinician until one or more signals from sensors return to within the homeostatic window, or until the magnitude of the electrical stimulation reaches an upper limit of a therapeutic window determined by the clinician. Similarly, upon detecting that one or more signals from sensors falls below the lower bound of the homeostatic window, the system decreases stimulation at a maximum ramp rate determined by the clinician until one or more signals from sensors return to within the homeostatic window, or until the magnitude of the electrical stimulation reaches a lower limit of a therapeutic window determined by the clinician. Upon detecting that one or more signals from sensors are within the threshold of the homeostatic window, the system holds the magnitude of the electrical stimulation constant.

[0090] Such a system **100** for delivering adaptive DBS to the patient by monitoring a physiological parameter may provide advantages over other techniques that use a neurological signal as a threshold in that the techniques of the disclosure allow an IMD to control delivery of therapy using hysteresis. In other words, such a system **100** uses the physiological parameter of the patient to create a control loop for not only controlling the delivery of therapy, but also controlling the magnitude of the delivered therapy. Such a system may be less intrusive on the activity of a patient because the system **100** adapts the stimulation to the current needs of the patient, and thus may reduce the side effects that the patient experiences.

[0091] Further, such a system **100** may use external sensors, such as accelerometers, instead of internal sensors, such as electrodes, to detect symptoms of the disease of the patient and control adjustments to the magnitude of one or more parameters of the therapy. For example, the system **100** may use a wrist sensor to detect wrist flexion or tremor of a patient suffering from Parkinson's disease. Thus, such an IMD the monitoring of a physiological parameter may be less invasive than other IMD systems because the system of the present disclosure may not require sensing electrodes to be implanted in the brain of the patient **112**.

[0092] In some circumstances, system **100**, as described herein, may deliver, based on the upper and lower threshold of the homeostatic window, a lower magnitude of electrical stimulation than patient **112** requires to prevent breakthrough of his or her symptoms. For example, a patient receiving therapy from an IMD **106** that controls delivery of electrical stimulation therapy using the homeostatic window may, in certain circumstances, experience results that are less optimal than if the patient received continuous electrical stimulation therapy at a maximum therapy magnitude. To prevent this occurrence, system **100** may determine a value for the at least one electrical stimulation parameter as defined by the homeostatic window, as described above. Further, the IMD **106** of system **100** may increase the value for the at least one electrical stimulation parameter by a bias amount greater than the determined magnitude defined by the homeostatic window so as to further prevent breakthrough of the symptoms of patient **112**. Thus, system **100** may avoid delivering electrical stimulation therapy that is of a magnitude that may be insufficient for prevention of symptom breakthrough.

[0093] The architecture of system **100** illustrated in FIG. **1** is shown as an example. The techniques as set forth in this disclosure may be implemented in the example system **100** of FIG. **1**, as well as other types of systems not described specifically herein. For example, a clinician may determine the upper threshold and lower threshold of the homeostatic window. In other examples, one of the external programmer **104** and IMD **104** determines the upper threshold and lower threshold of the homeostatic window. Furthermore, either external programmer **104** or IMD **106** may receive the signal representative of the signal of patient **112** and determine an adjustment to one or more parameters defining the electrical stimulation therapy that IMD **106** delivers to patient **112**. Nothing in this disclosure should be construed so as to limit the techniques of this disclosure to the example architecture illustrated by FIG. **1**.

[0094] FIG. **2** is a block diagram of the example IMD **106** of FIG. **1** for delivering adaptive deep brain stimulation therapy. In the example shown in FIG. **2**, IMD **106** includes processor **210**, memory **211**, stimulation generator **202**, sensing module **204**, switch module **206**, telemetry module **208**, sensor **212**, and power source **220**. Each of these modules may be or include electrical circuitry configured to perform the functions attributed to each respective module. For example, processor **210** may include processing circuitry, switch module **206** may include switch circuitry, sensing module **204** may include sensing circuitry, and telemetry module **208** may include telemetry circuitry. Switch module **204** may not be necessary for multiple current source and sink configurations. Memory **211** may include any volatile or non-volatile media, such as a random-access memory (RAM), read only memory (ROM), non-volatile RAM (NVRAM), electrically erasable programmable ROM (EEPROM), flash memory, and the like. Memory **211** may store computer-readable instructions that, when executed by processor **210**, cause IMD **106** to perform various functions. Memory **211** may be a storage device or other non-transitory medium.

[0095] In the example shown in FIG. **2**, memory **211** stores therapy programs **214** and sense electrode combinations and associated stimulation electrode combinations **218** in separate memories within memory **211** or separate areas within memory **211**. Each stored therapy program **214** defines a particular set of electrical stimulation parameters (e.g., a therapy parameter set), such as a stimulation electrode combination, electrode polarity, current or voltage amplitude, pulse width, and pulse rate. In some examples, individual therapy programs may be stored as a therapy

group, which defines a set of therapy programs with which stimulation may be generated. The stimulation signals defined by the therapy programs of the therapy group may be delivered together on an overlapping or non-overlapping (e.g., time-interleaved) basis.

[0096] Sense and stimulation electrode combinations **218** stores sense electrode combinations and associated stimulation electrode combinations. As described above, in some examples, the sense and stimulation electrode combinations may include the same subset of electrodes **116**, **118**, a housing of IMD **106** functioning as an electrode, or may include different subsets or combinations of such electrodes. Thus, memory **211** can store a plurality of sense electrode combinations and, for each sense electrode combination, store information identifying the stimulation electrode combination that is associated with the respective sense electrode combination. The associations between sense and stimulation electrode combinations can be determined, e.g., by a clinician or automatically by processor **210**. In some examples, corresponding sense and stimulation electrode combinations may comprise some or all of the same electrodes. In other examples, however, some or all of the electrodes in corresponding sense and stimulation electrode combinations may be different. For example, a stimulation electrode combination may include more electrodes than the corresponding sense electrode combination in order to increase the efficacy of the stimulation therapy. In some examples, as discussed above, stimulation may be delivered via a stimulation electrode combination to a tissue site that is different than the tissue site closest to the corresponding sense electrode combination but is within the same region, e.g., the thalamus, of brain **120** in order to mitigate any irregular oscillations or other irregular brain activity within the tissue site associated with the sense electrode combination.

[0097] Stimulation generator **202**, under the control of processor **210**, generates stimulation signals for delivery to patient **112** via selected combinations of electrodes **116**, **118**. An example range of electrical stimulation parameters believed to be effective in DB S to manage a movement disorder of patient include:

[0098] 1. Pulse Rate, i.e., Frequency: between approximately 40 Hertz and approximately 500 Hertz, such as between approximately 40 to 185 Hertz or such as approximately 140 Hertz.

[0099] 2. In the case of a voltage controlled system, Voltage Amplitude: between approximately 0.1 volts and approximately 50 volts, such as between approximately 2 volts and approximately 3 volts.

[0100] 3. In the alternative case of a current controlled system, Current Amplitude: between approximately 0.2 milliamps to approximately 100 milliamps, such as between approximately 1.3 milliamps and approximately 2.0 milliamps.

[0101] 4. Pulse Width: between approximately 10 microseconds and approximately 5000 microseconds, such as between approximately 100 microseconds and approximately 1000 microseconds, or between approximately 180 microseconds and approximately 450 microseconds.

[0102] Accordingly, in some examples, stimulation generator **202** generates electrical stimulation signals in accordance with the electrical stimulation parameters noted above, subject to application of the upper and lower threshold of a therapeutic window to one or more of the parameters, such that an applicable parameter resides within the range prescribed by the window. Other ranges of therapy parameter values may also be useful, and may depend on the target stimulation site within patient **112**. While stimulation pulses are described, stimulation signals may be of any form, such as continuous-time signals (e.g., sine waves) or the like.

[0103] Processor **210** may include fixed function processing circuitry and/or programmable processing circuitry, and may comprise, for example, any one or more of a microprocessor, a controller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), discrete logic circuitry, or any other processing circuitry configured to provide the functions attributed to processor **210** herein may be embodied as firmware, hardware, software or any combination thereof. Processor **210** may control stimulation generator **202** according to therapy programs **214** stored in memory **211** to apply particular stimulation parameter values specified by one or more of programs, such as voltage amplitude or current amplitude, pulse width, or pulse rate.

[0104] In the example shown in FIG. **2**, the set of electrodes **116** includes electrodes **116**A, **116**B, **116**C, and **116**D, and the set of electrodes **118** includes electrodes **118**A, **118**B, **118**C, and **118**D. Processor **210** also controls switch module **206** to apply the stimulation signals generated by stimulation generator **202** to selected combinations of electrodes **116**, **118**. In particular, switch module **204** may couple stimulation signals to selected conductors within leads **114**, which, in turn, deliver the stimulation signals across selected electrodes **116**, **118**. Switch module **206** may be a switch array, switch matrix, multiplexer, or any other type of switching module configured to selectively couple stimulation energy to selected electrodes **116**, **118** and to selectively sense neurological brain signals with selected electrodes **116**, **118**. Hence, stimulation generator **202** is coupled to electrodes **116**, **118** via switch module **206** and conductors within leads **114**. In some examples, however, IMD **106** does not include switch module **206**.

[0105] Stimulation generator **202** may be a single channel or multi-channel stimulation generator. In particular, stimulation generator **202** may be capable of delivering a single stimulation pulse, multiple stimulation pulses, or a continuous signal at a given time via a single electrode combination or multiple stimulation pulses at a given time via multiple electrode combinations. In some examples, however, stimulation generator **202** and switch module **206** may be configured to deliver multiple channels on a time-interleaved basis. For example, switch module **206** may serve to time divide the output of stimulation generator **202** across different electrode combinations at different times to deliver multiple programs or channels of stimulation energy to patient **112**. Alternatively, stimulation generator **202** may comprise multiple voltage or current sources and sinks that are coupled to respective electrodes to drive the electrodes as cathodes or anodes. In this example, IMD **106** may not require the functionality of switch module **206** for time-interleaved multiplexing of stimulation via different electrodes.

[0106] Electrodes **116**, **118** on respective leads **114** may be constructed of a variety of different designs. For example, one or both of leads **114** may include two or more electrodes at each longitudinal location along the length of the lead, such as multiple electrodes at different perimeter locations

around the perimeter of the lead at each of the locations A, B, C, and D. On one example, the electrodes may be electrically coupled to switch module **206** via respective wires that are straight or coiled within the housing the lead and run to a connector at the proximal end of the lead. In another example, each of the electrodes of the lead may be electrodes deposited on a thin film. The thin film may include an electrically conductive trace for each electrode that runs the length of the thin film to a proximal end connector. The thin film may then be wrapped (e.g., a helical wrap) around an internal member to form the lead **114**. These and other constructions may be used to create a lead with a complex electrode geometry.

[0107] Although sensing module **204** is incorporated into a common housing with stimulation generator **202** and processor **210** in FIG. **2**, in other examples, sensing module **204** may be in a separate housing from IMD **106** and may communicate with processor **210** via wired or wireless communication techniques. Example neurological brain signals include, but are not limited to, a signal generated from local field potentials (LFPs) within one or more regions of brain **28**. EEG and ECoG signals are other examples of electrical signals that may be measured within brain **120** or by electrodes placed in other locations with respect to brain **120**.

[0108] Sensor **212** may include one or more sensing elements that sense values of a respective patient parameter. For example, sensor **212** may include one or more accelerometers, optical sensors, chemical sensors, temperature sensors, pressure sensors, or any other types of sensors. Sensor **212** may output patient parameter values that may be used as feedback to control delivery of therapy. IMD **106** may include additional sensors within the housing of IMD **106** and/or coupled via one of leads **114** or other leads. In addition, IMD **106** may receive sensor signals wirelessly from remote sensors via telemetry module **208**, for example. In some examples, one or more of these remote sensors may be external to patient (e.g., carried on the external surface of the skin, attached to clothing, or otherwise positioned external to the patient).

[0109] Telemetry module **208** supports wireless communication between IMD **106** and an external programmer **104** or another computing device under the control of processor **210**. Processor **210** of IMD **106** may receive, as updates to programs, values for various stimulation parameters such as magnitude and electrode combination, from programmer **104** via telemetry module **208**. The updates to the therapy programs may be stored within therapy programs **214** portion of memory **211**. Telemetry module **208** in IMD **106**, as well as telemetry modules in other devices and systems described herein, such as programmer **104**, may accomplish communication by radiofrequency (RF) communication techniques. In addition, telemetry module **208** may communicate with external medical device programmer **104** via proximal inductive interaction of IMD **106** with programmer **104**. Accordingly, telemetry module **208** may send information to external programmer **104** on a continuous basis, at periodic intervals, or upon request from IMD **106** or programmer **104**.

[0110] Power source **220** delivers operating power to various components of IMD **106**. Power source **220** may include a small rechargeable or non-rechargeable battery and a power generation circuit to produce the operating power. Recharging may be accomplished through proximal inductive interaction between an external charger and an inductive charging coil within IMD **220**. In some examples, power requirements may be small enough to allow IMD **220** to utilize patient motion and implement a kinetic energy-scavenging device to trickle charge a rechargeable battery. In other examples, traditional batteries may be used for a limited period of time.

[0111] According to the techniques of the disclosure, processor **210** of IMD **106** delivers, electrodes **116**, **118** interposed along leads **114** (and optionally switch module **206**), electrical stimulation therapy to patient **112**. The adaptive DBS therapy is defined by one or more therapy programs **214** having one or more parameters stored within memory **211**. For example, the one or more parameters include a current amplitude (for a current-controlled system) or a voltage amplitude (for a voltage-controlled system), a pulse rate or frequency, and a pulse width, or quantity of pulses per cycle. In examples where the electrical stimulation is delivered according to a "burst" of pulses, or a series of electrical pulses defined by an "on-time" and an "off-time," the one or more parameters may further define one or more of a number of pulses per burst, an on-time, and an off-time. In one example, the therapeutic window defines an upper limit and a lower limit for a voltage amplitude of the electrical stimulation therapy. In another example, the therapeutic window defines an upper limit and a lower limit for a current amplitude of the electrical stimulation therapy. In particular, a parameter of the electrical stimulation therapy, such as voltage or current amplitude, is constrained to a therapeutic window having an upper limit and a lower limit, such that the voltage or current amplitude may be adjusted provided the amplitude remains greater than or equal to the lower limit and less than or equal to the upper limit. It is noted that a single limit may be used in some examples.

[0112] In one example, processor **210**, via electrodes **116**, **118** of IMD **106**, monitors the behavior of a signal of patient **112** that correlates to one or more symptoms of a disease of patient **112** within a homeostatic window. Processor **210**, via electrodes **116**, **118**, delivers to patient **112** adaptive DBS and may adjust one or more parameters defining the electrical stimulation within a parameter range defined by lower and upper thresholds of a therapeutic window based on the activity of the sensed signal within the homeostatic window.

[0113] In one example, the signal is a neurological signal (e.g., a LFP signal) within the Beta frequency band of brain **120** of patient **112**. The signal within the Beta frequency band of patient **112** may correlate to one or more symptoms of Parkinson's disease in patient **112**. Generally speaking, neurological signals within the Beta frequency band of patient **112** may be approximately proportional to the severity of the symptoms of patient **112**. For example, as tremor induced by Parkinson's disease increases, one or more of electrodes **116**, **118** detect an increase in the magnitude of neurological signals within the Beta frequency band of patient **112**.

[0114] Similarly, as tremor induced by Parkinson's disease decreases, processor **210**, via the one or more of electrodes **116**, **118**, detects a decrease in the magnitude of the neurological signals within the Beta frequency band of patient **112**. In another example, the signal is a neurological signal within the Gamma frequency band of brain **120** of patient **112**. The signal within the Gamma frequency band of patient **112** may also correlate to one or more side effects of the electrical stimulation therapy. However, in contrast to neu-

rological signals within the Beta frequency band, generally speaking, neurological signals within the Gamma frequency band of patient **112** may be approximately inversely proportional to the severity of the side effects of the electrical stimulation therapy. For example, as side effects due to electrical stimulation therapy increase, processor **210**, via the one or more of electrodes **116**, **118**, detects a decrease in the magnitude of the signal within the Gamma frequency band of patient **112**. Similarly, as side effects due to electrical stimulation therapy decrease, processor **210**, via the one or more of electrodes **116**, **118**, detects an increase in the magnitude of the signal within the Gamma frequency band of patient **112**.

[0115] In response to detecting that the signal of the patient, e.g., a sensed physiological parameter signal or a sensed neurological signal, has deviated from the homeostatic window, processor **210** dynamically adjusts the magnitude of the one or more parameters of the electrical stimulation therapy such as, e.g., pulse current amplitude or pulse voltage amplitude, to drive the signal of the patient back into the homeostatic window. For example, wherein the signal is a neurological signal within the Beta frequency band of brain **120** of patient **112**, processor **210**, via the one or more of electrodes **116**, **118**, monitors the beta magnitude of patient **112**. Upon detecting that the beta magnitude of patient **112** exceeds the upper bound of the homeostatic window, processor **210** increases a magnitude of the electrical stimulation delivered via electrodes **116**, **118** at a maximum ramp rate, e.g., determined automatically or by the clinician until the magnitude of the neurological signal within the Beta band falls back to within the homeostatic window, or until the magnitude of the electrical stimulation reaches an upper limit of a therapeutic window determined by the clinician. Similarly, upon detecting that the beta magnitude of patient **112** falls below the lower bound of the homeostatic window, processor **210** decreases stimulation magnitude at a maximum ramp rate determined by the clinician until the beta magnitude rises back to within the homeostatic window, or until the magnitude of the electrical stimulation reaches a lower limit of a therapeutic window determined by the clinician. Upon detecting that the beta magnitude is presently within the threshold of the homeostatic window, or has returned to within the threshold of the homeostatic window, processor **210** holds the magnitude of the electrical stimulation constant. In other examples, processing **210** may automatically determine the ramp rate at which stimulation parameters are adjusted to cause the brain signal to fall back within the target range. The ramp rate may be selected based on prior data indicating general patient comfort or comfort or preferences of the specific patient.

[0116] In some examples, processor **210** continuously measures the signal in real time. In other examples, processor **210** periodically samples the signal according to a predetermined frequency or after a predetermined amount of time. In some examples, processor **210** periodically samples the signal at a frequency of approximately **150** Hertz.

[0117] Furthermore, processor **210** delivers electrical stimulation therapy that is constrained by an upper limit and a lower limit of a therapeutic window. In some examples, values defining the therapeutic window are stored within memory **211** of IMD **106**. For example, in response to detecting that the brain signal has deviated from the homeostatic window, processor **210** of IMD **106** may adjust one or more parameters of the electrical stimulation therapy to provide responsive treatment to patient **112**. For example, in response to detecting that the signal has exceeded an upper threshold of the homeostatic window and prior to delivering the electrical stimulation therapy, processor **210** increases an amplitude of stimulation (e.g., but not above the upper limit) in order to bring the signal back down below the upper threshold. For example, in a voltage-controlled system wherein the clinician has set the upper limit of the therapeutic window to be 3 Volts, processor **210** can increase the voltage amplitude to values no greater than 3 Volts in an attempt to decrease the brain signal below the upper threshold.

[0118] In another example, in response to detecting that the signal has fallen below a lower threshold of the homeostatic window and prior to delivering the electrical stimulation therapy, processor **210** decreases the voltage amplitude, for example, but not lower than the magnitude of the lower limit. For example, in the above voltage-controlled system wherein the clinician has set the lower bound of the therapeutic window to be 1.2 Volts, processor **210** can decrease the voltage amplitude down to no lower than 1.2 Volts in an attempt to raise the brain signal back above the lower threshold and into the homeostatic window. Thus, processor **210** of IMD **106** may deliver adaptive DBS to patient **112** wherein the one or more parameters defining the adaptive DBS is within the therapeutic window defined by a lower and upper limit for the parameter.

[0119] In the foregoing example, the limit of the therapeutic window are inclusive (i.e., the upper and lower limit are valid values for the one or more parameters). However, in other examples, the limit of the therapeutic window are exclusive (i.e., the upper and lower limits are not valid values for the one or more parameters). In such an example of an exclusive therapeutic window, processor **210** instead sets the adjustment to the one or more parameters to be the next highest valid value (in the case of an adjustment potentially exceeding the upper limit) or the next lowest valid value (in the case of an adjustment potentially exceeding the lower limit).

[0120] In another example, values defining the therapeutic window are stored within a memory **311** of external programmer **104**. In this example, in response to detecting that the signal has deviated from the homeostatic window, processor **210** of IMD **106** transmits, via telemetry module **208**, data representing the measurement of the signal to external programmer **104**. In one example, in response to detecting that the signal has exceeded an upper threshold of the homeostatic window, processor **210** of IMD **106** transmits, via telemetry module **208**, data representing the measurement of the signal to external programmer **104**. External programmer **104** may determine to adjust a parameter value to reduce the signal below the upper threshold as long as the parameter value remains within the one or more limits to the parameter.

[0121] In another example, processor **210**, via telemetry module **208** and from external programmer **104**, receives instructions to adjust one or more limits of the therapeutic window. For example, such instructions may be in response to patient feedback on the efficacy of the electrical stimulation therapy, or in response to one or more sensors that have detected a signal of the patient. Such signals from sensors may include neurological signals, such as a signal within the Beta frequency band or signal within the Gamma frequency band of brain **120** of patient **112**, or physiological

parameters and measurements, such as a signal indicating one or more of a patient activity level, posture, and respiratory function. Further, such signals from sensors may indicate a lack of reduction of one or more symptoms of the patient **112**, such as tremor or rigidity or the presence of side effects due to electrical stimulation therapy, such as paresthesia. In response to these instructions, processor **210** may adjust one or more thresholds of the homeostatic window. For example, processor **210** may adjust the magnitude of the upper threshold, the lower threshold, or shift the overall position of the homeostatic window such that the threshold, defined by the homeostatic window, for adjustment of the one or more parameters of electrical stimulation, is itself adjusted. Thereafter, processor **210**, via electrodes **116** and **118**, delivers the adjusted electrical stimulation to patient **112**.

[0122] FIG. **3** is a block diagram of the external programmer **104** of FIG. **1**. Although programmer **104** may generally be described as a hand-held device, programmer **104** may be a larger portable device or a more stationary device. In some examples, programmer **104** may be referred to as a tablet computing device. In addition, in other examples, programmer **104** may be included as part of an external charging device or include the functionality of an external charging device. As illustrated in FIG. **3**, programmer **104** may include a processor **310**, memory **311**, user interface **302**, telemetry module **308**, and power source **320**. Memory **311** may store instructions that, when executed by processor **310**, cause processor **310** and external programmer **104** to provide the functionality ascribed to external programmer **104** throughout this disclosure. Each of these components, or modules, may include electrical circuitry that is configured to perform some or all of the functionality described herein. For example, processor **310** may include processing circuitry configured to perform the processes discussed with respect to processor **310**.

[0123] In general, programmer **104** comprises any suitable arrangement of hardware, alone or in combination with software and/or firmware, to perform the techniques attributed to programmer **104**, and processor **310**, user interface **302**, and telemetry module **308** of programmer **104**. In various examples, programmer **104** may include one or more processors, which may include fixed function processing circuitry and/or programmable processing circuitry, as formed by, for example, one or more microprocessors, DSPs, ASICs, FPGAs, or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components. Programmer **104** also, in various examples, may include a memory **311**, such as RAM, ROM, PROM, EPROM, EEPROM, flash memory, a hard disk, a CD-ROM, comprising executable instructions for causing the one or more processors to perform the actions attributed to them. Moreover, although processor **310** and telemetry module **308** are described as separate modules, in some examples, processor **310** and telemetry module **308** may be functionally integrated with one another. In some examples, processor **310** and telemetry module **308** correspond to individual hardware units, such as ASICs, DSPs, FPGAs, or other hardware units.

[0124] Memory **311** (e.g., a storage device) may store instructions that, when executed by processor **310**, cause processor **310** and programmer **104** to provide the functionality ascribed to programmer **104** throughout this disclosure. For example, memory **311** may include instructions that cause processor **310** to obtain a parameter set from memory, select a spatial electrode movement pattern, or receive a user input and send a corresponding command to IMD **104**, or instructions for any other functionality. In addition, memory **311** may include a plurality of programs, where each program includes a parameter set that defines stimulation therapy.

[0125] User interface **302** may include a button or keypad, lights, a speaker for voice commands, a display, such as a liquid crystal (LCD), light-emitting diode (LED), or organic light-emitting diode (OLED). In some examples the display may be a touch screen. User interface **302** may be configured to display any information related to the delivery of stimulation therapy, identified patient behaviors, sensed patient parameter values, patient behavior criteria, or any other such information. User interface **302** may also receive user input via user interface **302**. The input may be, for example, in the form of pressing a button on a keypad or selecting an icon from a touch screen. User interface **302** may refer to hardware configured to present information to a user and/or receive input from the user. In some examples, processor **310** directly controls this hardware. In other examples, processor **310** may communicate with drive hardware that controls hardware of user interface **302**. In some example, user interface **302** may include display and/or interactive display configurations as described herein.

[0126] Telemetry module **308** may support wireless communication between IMD **106** and programmer **104** under the control of processor **310**. Telemetry module **308** may also be configured to communicate with another computing device via wireless communication techniques, or direct communication through a wired connection. In some examples, telemetry module **308** provides wireless communication via an RF or proximal inductive medium. In some examples, telemetry module **308** includes an antenna, which may take on a variety of forms, such as an internal or external antenna.

[0127] Examples of local wireless communication techniques that may be employed to facilitate communication between programmer **104** and IMD **106** include RF communication according to the 802.11 or Bluetooth specification sets or other standard or proprietary telemetry protocols. In this manner, other external devices may be capable of communicating with programmer **104** without needing to establish a secure wireless connection. As described herein, telemetry module **308** may be configured to transmit a spatial electrode movement pattern or other stimulation parameter values to IMD **106** for delivery of stimulation therapy.

[0128] According to the techniques of the disclosure, in some examples, processor **310** of external programmer **104** defines the parameters of a homeostatic therapeutic window, stored in memory **311**, for delivering adaptive DBS to patient **112**. In one example, processor **311** of external programmer **104**, via telemetry module **308**, issues commands to IMD **106** causing IMD **106** to deliver electrical stimulation therapy via electrodes **116**, **118** via leads **114**.

[0129] The following examples illustrate various user interfaces and techniques for managing the sensing of physiological signals, such as brain signals, and managing electrical stimulation as described above. Programmer **104**, or another external computing device, may output the user interfaces and screens described herein. FIG. **4** is a conceptual diagram illustrating an example home screen **402** for

navigating within an example user interface **400**. User interface **400** may include several different screens as the user can navigate to different functions to view sensed information, view stored data, or adjust various stimulation parameter values. As shown in the example of FIG. **4**, home screen **402** includes information associated with patient **122**, such as patient specific information **406** such as name, patient ID, date of birth, and patient diagnosis. Other information may include device specific information such as model number, implant date, battery level, and estimated batter life remaining. Information such as impedance status for the system and event summary may also be provided in the home screen **402**. Screen **402** may also include stimulation toggle switch **404** that, when selected, toggles between turning stimulation on or turning stimulation off. Stimulation toggle switch **404** may be provided in some, most, or all of the different screens within user interface **400** to enable the user to turn stimulation on or off at any time. Alert button **410** shows "no alerts" because there are no alerts to be shown. However, if there are alerts for the user, alert button **410** may indicate that there are alerts, or the number of alerts, and alert button **410** may be selectable to cause user interface **400** to show a list of the alerts for the user.

[0130] The home screen **402** in FIG. **4** may also include a menu **408** that includes several selectable buttons that enable a user to navigate to other screen and functionality supported by user interface **400**. These selectable buttons include "setup," "stimulation," "impedance," "MRI eligibility," "replacement," "events," and "end session." Programmer **104** may switch to the appropriate screen in response to user selection of the respective selectable button.

[0131] The setup button takes the user to screens associated with selecting electrode configurations for sensing and/or stimulation. The setup portion of user interface **400** may also provide screens that receive user input for capturing upper and/or lower thresholds for a homeostatic window and/or upper and/or lower limits for the therapeutic window. The stimulation button takes the user to screens associated with managing electrical stimulation therapy for the patient. The impedance button takes the user to screens associated with viewing impedances of one or more electrode combinations and/or leads and running impedance testing for any electrical pathways.

[0132] The MRI eligibility button takes the user to screens associated with checking MRI eligibility of any implanted device (e.g., IMD **106**) and/or placing the implanted device into an MRI eligible mode. The replacement button causes user interface **400** to displace screens related to when the IMD **106** should be replaced (e.g., remaining operational life for a primary cell non-rechargeable power supply). The events button enables the user to navigate to various screens that display events and data associated with sensing and delivering electrical stimulation. The end session button enables a user to terminate the management session via user interface **400**. In addition to the menu, user interface **400** may include a stimulation toggle switch that enables the user to request turning stimulation on or off.

[0133] User interface **400** may be configured for a clinician programmer that enables a clinician to manage all aspects of stimulation therapy and/or sensing. In some examples, user interface **400** may enable the language of the clinician programmer to be different from a patient programmer configured to enable the patient to control a subset of features related to IMD **106**. For example, user interface **400** may enable the clinician to set up the patient programmer language in the setup button, where the patient programmer language is different from the language of user interface **400** presented by the clinician programmer. For example, user interface **400** may enable the clinician to set up therapy group names, device names, and patient events to appear in a patient's local language irrespective of the primary or supported clinician language of user interface **400**. In this manner, user interface **400** may enable the clinician (or a translator assisting the clinician) to program group names and patient events in the desired language for the patient even if it is not the primary language of the clinician.

[0134] FIGS. **5** and **6** are conceptual diagrams illustrating example setup screens for managing electrode configurations. Programmer **104** may be configured to control display of user interface **400** that includes screens for reviewing and selecting electrode configurations for sensing brain signals. In some examples, programmer **104** may control IMD **106** to check signal quality across all electrodes and leads (e.g., in different hemispheres) for the purpose or guiding the user to selection of an appropriate sensing electrode configuration. This appropriate sensing configuration may also be appropriate for stimulation because the sensing electrode configuration may be compatible with an efficacious stimulation electrode configuration for therapy.

[0135] In some examples, programmer **104** may evaluate all constraints and known information of stimulation outcomes, such as electrode impedances, signal powers in one or more frequency bands, electrode combinations selected for therapy, or other such factors. For example, for each lead or hemisphere, programmer **104** may suggest a sensing electrode configuration based on one, some, or all of the following factors: electrodes available for sensing due to concurrent stimulation electrodes used, sensed signals of interest (e.g., one or more of a predetermined signal range or a peak power for a specific frequency band such as a Beta or Gamma band), previously collected information regarding effects and/or side effects for various electrodes at certain stimulation parameter values (e.g., as shown in FIGS. **8** and **9**), or identified sources of artifacts due to other signals such as electrocardiogram (ECG) artifacts.

[0136] User interface **400** may include configuration options that enable a user to configure, or adjust, one or more aspects of sensing electrode configuration setup process. For example, programmer **104** may provide a frequency selection input (as shown in FIG. **10**) that adjusts the frequency of signals for feedback in response the user selecting a different frequency. Programmer **104** may provide this frequency selection input for one or more frequency bands, such as the Beta band and Gamma band. In addition, user interface **400** may provide selectable inputs that enable the user to adjust the frequency of a high pass filter or type of filter, sensing blanking duration, averaging duration for the signal, or whether or not electrodes (or electrode combinations) that capture artifacts (e.g., ECG or EMG artifacts) can be selectable for sensing brain signals (e.g., as shown in FIG. **11**). In other examples, user interface **400** may enable artifact contrast input that may enable a user specified magnitude of artifact (or several selectable levels of artifact) to be acceptable for sensing electrode configurations.

[0137] In some examples, user interface **400** may provide additional features. For example, programmer **104** may include different default settings for sensing electrode con-

figuration setup based on the indication of therapy for the patient. For example, the user may input the specific type of condition or therapy desired (e.g., Parkinson's disease, tremor, epilepsy, depression, etc.), and programmer **104** may control user interface **400** to set default settings for the sensing electrode configurations (e.g., target frequency bands, electrode configurations, filters, blanking intervals, averaging durations, etc.) that may reduce adjustments needed from the user. Programmer **104** may also include automatic selection of frequency band powers when multiple peaks are present in a certain frequency band. For example, programmer **104** may be configured to select one of the multiple peaks for sensing based on the magnitude of each peak with respect to adjacent frequencies, the position of the frequencies within respect to commonly used frequencies, the closeness of peaks to each other, or any other such factors. In some examples, programmer **104** may set or suggest (for user confirmation) a specific bandwidth for sensing the power of sensed signals. This specific bandwidth may be set to a predetermined, and fixed, range such as **5** Hz, for example. However, programmer **104** may select a different fixed range based on the frequency width of a power peak in the power spectrum, the presence of neighboring peaks, the absence of neighboring peaks, or indication of the patient. In some examples, programmer **104** may enable a bandwidth selection input that is configured to receive user input selecting a different frequency range desired by the user (e.g., less or greater than the suggested bandwidth). Such a bandwidth input could be provided as a slider or other input on FIG. **10**, for example. User interface **400** may show the changed bandwidth on the graph by widening or narrowing a column of different color around the target frequency shown.

[0138] In another example, programmer **104** may suggest different default settings for signal quality based on the type of lead selected (or indicated as implanted in the patient). For example, programmer **104** may use different electrode combinations for sensing from a lead with all ring electrodes than a lead with some electrodes at different circumferential positions around the lead. In addition, programmer **104** may change filter settings, blanking durations, averaging durations, frequency bands, etc. based on the type of lead indicated as implanted within the patient.

[0139] In the example of FIG. **5**, the BrainSense setup screen **502** has been entered in order to select the electrode configuration for sensing brain signals, such as LFP signals. Menu **504** indicates the current stage in the setup, which is shown as "BrainSenseSetup" in FIG. **5**. As the user moves through the different stages of the setup, the respective stage is underlined to show the current status. The "refresh signal test" button **506** causes, when selected by a user, programmer **104** to control IMD **106** to run a signal test on one or more pathways (e.g., different electrode combinations). Each pathway is a different electrode combination possible for the electrodes implanted within the patient. For each pathway, IMD **106** gathers brain signals for a period of time, such as 30 seconds. Each pathway may be a pathway between two or more different electrodes of the lead (e.g., a sensing electrode combination).

[0140] The screen of FIG. **5** may display all pairs of electrode combinations a particular lead. Lead selector **508** indicates which lead, or hemisphere in which the lead is located, has been selected (e.g., the left STN in the example of FIG. **5**). Although a four electrode lead is shown in the example of FIG. **5**, other leads having fewer or greater numbers of electrodes can be used in other examples. In some examples, the lead may have multiple electrodes located at different circumferential positions around the perimeter of the lead alone or in combination with ring electrodes or other electrode patterns. FIG. **5** illustrates a screen in which all pathways (or all sensing electrode combinations) are shown on respective selectable cards **510**. Each card **510** may provide the frequency of the brain signal that provides the greatest amplitude. For example, the selected card **510**A in FIG. **5** indicates a frequency of **22.46** Hz that is within the Beta frequency band. No signal has been selected for the respective different pathways of cards **510**B and **510**C. In other examples, user interface **400** may be controlled to only show the cards of pathways that provide better signal when there are too many pathways to show on the screen of FIG. **5**. In other examples, user interface **400** may group combinations according to type of electrode combinations (e.g., which position the electrodes are in the lead) or other factors. Advanced settings **518** is a selectable icon that, when selected, causes programmer **104** to show additional settings for stimulation.

[0141] In this manner, processing circuitry **310** of programmer **104** may be configured to obtain brain signal information for at least one electrode combination of a plurality of electrode combinations of one or more electrical leads, determine, based on the brain signal information, a respective frequency for the at least one electrode combination, and output, for display, a plurality of selectable lead icons (e.g., cards **510**), wherein each selectable lead icon of the plurality of selectable lead icons represents a different electrode combination of the plurality of electrode combinations. In addition, processing circuitry **310** may output, for display, the respective frequency determined for the at least one electrode combination in association with the respective selectable lead icon associated with the at least one electrode combination, receive user input selecting one selectable lead icon of the plurality of selectable lead icons, and, responsive to receiving the user input, select, for subsequent brain signal sensing, a sense electrode combination associated with the one selectable lead icon selected by the user input.

[0142] Processing circuitry **310** may also output, for display, a selectable signal test icon, receive user input selecting the selectable signal test icon, and responsive to receiving the user input selecting the selectable signal test icon, control a medical device to obtain brain signal information for at least one electrode combination of the plurality of electrode combinations. The plurality of electrode combinations may include all electrode combinations possible for the one or more electrical leads implanted within a patient, but less than all combinations may be shown in other examples.

[0143] In some examples, processing circuitry **310** may analyze the brain signal information for presence of an artifact associated with at least one of electrocardiogram sensing or motion of the one or more electrical leads, determine that the artifact is not present in the brain signal information, and, responsive to determining that the artifact is not present, approving the one or more electrode combinations for selection by a user for subsequent brain signal sensing. In this manner, processing circuitry **310** may determine if an electrode or electrode combination may be suited for sensing or potentially problematic and unable to provide accurate and/or consistent sensed data. Processing circuitry

310 may perform the ECG artifact detection in several different ways, alone or in combination. In some examples, processing circuitry **310** analyzes the brain signal information for presence of the artifact by applying a logistic regression classifier to at least a portion of the brain signal information. This logistic regression classifier may be a machine learning approach using LFP data collected from prior group of patients for training. Other types of machine learning algorithms may be used in other examples, such as neural networks, support vector machines, extra trees, random forests, or other types of classifiers.

[0144] A logistic regression classifier may include spectral band power features and time domain threshold crossing statistic features. Processing circuitry **310** may initially filter the sensed brain signal, such as removing a first portion (e.g., 10 seconds) and a last portion (e.g., 2.5 seconds) to avoid transient signals. Processing circuitry **310** may determine spectral features by computing band power over several frequency intervals. In one example, these frequency bands may include 0-3 Hz, 3-5 Hz, 5-10 Hz, 10-20 Hz, 20-30 Hz, 40-50 Hz, 50-60 Hz, 70-80 Hz, and 80-90 Hz. Processing circuitry **310** may then normalize the power by dividing the power for each band by the total power calculated in the band from 0-90 Hz. Processing circuitry **310** may then compute the entropy of normalized band powers. In some examples, the entropy of normalized band powers will be summed for used by the logistic regression classifier.

[0145] The time domain features may be determined by computing the threshold crossings from the rectified normalized LFP signal. Processing circuitry **310** may determine the rate of threshold crossings for several different thresholds. Processing circuitry **310** may then determine the inter threshold crossing interface (e.g., the number of seconds between consecutive threshold crossings. Processing circuitry **310** may then determine the entropy for each inter threshold crossing interval. These time domain features may be used in addition to the spectral features by the logistic regression classifier or other machine learning algorithms in other examples.

[0146] The inputs for the logistic regression classifier may include an amplitude or power from selected frequency ranges of a brain signal such that frequency domain and/or time domain inputs may be employed. In one example, processing circuitry **310** may determine a plurality of signal features from the brain signal information, the plurality of signal features including entropies for a plurality of frequency bands within the brain signal information and a plurality of time domain threshold crossing features. Then, processing circuitry **310** may apply the logistic regression classifier to the portion of the brain signal information by applying the logistic regression classifier to the plurality of signal features. In some examples, the probability threshold for the logistic regression classifier may be set to 0.5, wherein anything greater than 0.5 is output as the brain signal including an ECG artifact and anything 0.5 or less is output as the brain signal not including an ECG artifact.

[0147] As another way of identifying ECG artifacts, processing circuitry **310** may analyze the brain signal information for a fast Fourier transform (FFT) amplitude separation at approximately 8 Hz between a first brain signal detected during delivery of electrical stimulation and a second brain signal detecting during an absence of electrical stimulation delivery. In this manner, the FFT amplitude separation less than a separation threshold indicates that the artifact is not present. In some examples, IMD **106** may be more susceptible to ECG artifact with stimulation being delivered at 0 mA, so this check helps to identify those cases. In one example, the absolute value of the FFT amplitude difference at 8 Hz between stimulation off and stimulation at **0** mA is compared to a threshold (e.g., 200 nV/rtHz). If this FFT amplitude difference is greater than the threshold, then the system determines that the separation is too large and the electrode configuration is susceptible to ECG artifacts.

[0148] In this manner, processing circuitry **310** may evaluate the recorded brain signal from each electrode combination for several issues. Processing circuitry **310** may evaluate the brain signal to determine that no ECG artifact is present. In addition, processing circuitry **310** may analyze the brain signal to determine that no movement artifacts are present. In addition, processing circuitry **310** may determine that the brain signal amplitude is above a predetermined threshold. For the example of LFP signals, the threshold may be 1.2 uVp (microvolt peak).

[0149] Processing circuitry **310** may automatically select the frequency from the brain signal that has the largest amplitude, or power, in the frequency domain. This frequency may then be used by the electrode combination to monitor changes to the brain signal. However, user interface **400** may receive user selection of an edit button that enables the user to select a different frequency from the automatically selected frequency. For example, the user may select the frequency from a graph of power vs. frequency from the test signal for the electrode combination.

[0150] The "review" button **512** provides a summary about effects, side effects, amplitudes, etc. that has already been established by a clinician for this pathway and for the specific patient. For example, the clinician may have previously performed a monopolar review of all electrode pathways in order to identify any effects and side effects associated with stimulation for each electrode. In this manner, the user may be able to access these annotations about each electrode combination from the card for that specific electrode combination. The user may then be able to balance sensing with therapy. For example, the user can select a different electrode combination based on information other than the frequencies of the sensed brain signal for that electrode combination.

[0151] Once the electrode configuration has been selected, the user can select "save and exit" button **514** which causes processing circuitry **310** to enter a different screen where sensing and therapy can begin. Alternatively, processing circuitry **310** may receive user selection of the "next" button **516** and responsively move to the next screen in which thresholds may be established for adaptive DBS therapy. In the example of FIG. **6**, screen **602** is similar to screen **502** and illustrates that the highlighted card **510**A of the selected electrode combination indicates that therapy is being delivered using the electrode combination of the selected card **510**A.

[0152] FIG. **7** is a flowchart illustrating an example technique for running a signal test that evaluates one or more aspects of an electrode configuration. The signal test is configured to assess the presence and/or prevalence of particular brain signals across all available electrode configurations to a medical device. Such a process may utilize portions of user interface **400** shown in FIGS. **4**, **5**, and **6**.

[0153] In the example if FIG. **7**, processing circuitry **310** obtains brain signal information for at least one electrode

combination of a plurality of electrode combinations of one or more electrical leads (**702**) and then determines, based on the brain signal information, a respective frequency for the at least one electrode combination (**704**). Example signals obtained during this process may be similar to the signals shown in FIGS. **58** and **59**. Processing circuitry **310** then outputs, for display, a plurality of selectable lead icons (**706**), such as selectable cards **510** of FIG. **5**. Each selectable lead icon of the plurality of selectable lead icons represents a different electrode combination of the plurality of electrode combinations. Processing circuitry **310** then outputs, for display, the respective frequency determined for the at least one electrode combination in association with the respective selectable lead icon associated with the at least one electrode combination (**708**). Processing circuitry **310** receives user input selecting one selectable lead icon of the plurality of selectable lead icons (**710**) and, responsive to receiving the user input, selects, for subsequent brain signal sensing, a sense electrode combination associated with the one selectable lead icon selected by the user input (**712**). The user may repeat this process at any time during therapy or monitoring of the patient.

[0154] FIGS. **8** and **9** are conceptual diagrams illustrating example user interface screens **802** and **902** illustrating information associated with stimulation effects for a patient. The information of FIGS. **8** and **9** of user interface **400** may provide accessibility to previously captured clinician evaluation of electrode viability for one or more electrode combinations. In some examples, the previously captured clinician evaluation may have been performed using monopolar electrode combinations (e.g., one electrode on a lead and another electrode distal from the lead, such as an electrode carried by the housing of the IMD). By providing this evaluation information for electrodes as integrated with the signal selection and evaluation process, the clinician and/or automated system, may have quick access to additional background information when making the most appropriate signal selection for sensing and/or stimulation. The screens of FIGS. **8** and **9** may be accessed via the "review" button **512** from FIG. **5**.

[0155] As shown in FIG. **8**, screen **802** displays the severity of various side effects, such as bradykinesia, muscle contractions, and paresthesia in data field **808**, for respective stimulation parameter sets **806**. Each parameter set **810** shows values of amplitude, pulse width, and frequency. Each data point for the various side effects may include a numerical indicator, a word indicator, and/or a graph indicator. Menu **804** indicates that screen **802** shows the table of this information. As shown in the example of FIG. **9**, screen **902** illustrates an example graph **904** showing the severity of side effects in conjunction with the severity of symptoms for different current amplitudes of stimulation. Each graph is provided for a single day, but multiple days may be combined in other examples. Parameter values **906** indicate the pulse width and frequency for the delivered stimulation. Menu **804** indicates that screen **802** shows the graph version of this information.

[0156] Programmer **104** may utilize historical data for the patient, or other patients with similar conditions, when generating a suggested sensing electrode configuration. For example, programmer **104** may identify those electrode combinations that can provide efficacious therapy (e.g., therapeutic effects with no or limited side effects) and suggest only sensing configurations compatible with those electrode combinations for therapy. Programmer **104** may identify those electrode combinations that would not be used for therapy. In some examples, programmer **104** may control user interface **400** may indicate which sensing electrodes are available for the stimulation electrode combinations that can provide effective therapy. The screens **802** and **902** of FIGS. **8** and/or **9** may also indicate the therapeutic windows, thresholds, or other stimulation parameters associated with the identified electrode combinations. Programmer **104** may control the user interface to present a therapeutic window, for example, for each electrode combination when available to identify those electrode combinations that can provide larger therapeutic windows and likely better stimulation therapy.

[0157] FIG. **10** is a conceptual diagram illustrating an example screen **1000** for adjusting a frequency band used for sensing brain signals using an electrode configuration. As shown in FIG. **10**, the brain signal **1010** recorded for an electrode configuration during the signal check of FIG. **5** is shown in the frequency domain. Processing circuitry **310** has automatically selected the frequency **1012** having a peak **1008** in the Beta frequency band **1002** as the frequency from which to monitor during brain signal sensing. Frequency indicator **1006** indicates that this frequency is 22.46 Hz. This peak **1008** may be selected because it may provide the best sensing for changes to brain signal information. However, via the screen **1000** of FIG. **10**, the user interface **400** provides a user movable slider **1016** that, when selected, enables the user to drag slider **1016** along the x-axis and select a different frequency. Frequency range **1014** indicates the range of frequencies from which the power of signal **1010** will be used to monitor brain activity. In some examples, frequency range **1014** may be a preset variance from frequency **1012**, such as 5 Hz on either side of frequency **1012**. In other examples, screen **1000** may include an adjustment input via which the user can change frequency range **1014**. In other examples programmer **104** may automatically select the width of frequency range **1014** based on the width of peak **1008** or some other feature of signal **1010**. Although both Beta band **1002** and Gamma band **10004** are shown, other examples may only include one frequency band. In response to user selection of close button **1018**, user interface **400** may close screen **1000** and return to a setup screen such as screen **502**.

[0158] FIG. **11** is a conceptual diagram illustrating an example screen **1100** for setting various sensing parameters for an electrode configuration. As shown in the example of FIG. **11**, user interface **400** may provide screen **100** which includes sensing parameters such as the frequency of the high pass filter **1102**, the sensing blanking duration **1104**, and the average duration for sensing **1106**. Each of these parameters may be selected and changed by a user. In addition, the user may be able to determine whether or not electrode combinations that include artifacts are selectable for sensing, via selection of one of the allow artifacts input boxes **1108**.

[0159] FIG. **12** is a conceptual diagram illustrating an example screen **1200** for selecting a type of adaptive DBS mode. As shown in the example of FIG. **12**, user interface **400** may include a screen **1200** that enables selection of dual threshold mode **1202**, single threshold mode **1204**, or single threshold inverse mode **1206**. Dual threshold mode **1202** is shown as selected. Dual threshold mode **1202** enables the system to adjust stimulation amplitude based on upper and

lower thresholds of the LFP signals. Single threshold mode **1204** enables the system to increase stimulation when LFP signals are above the threshold, and single threshold inverse mode **1206** enables the system to decrease stimulation when LFP signals are below the threshold.

[0160] This feature of adaptive DBS is intended to allow a clinician to configure therapy to automatically adjust, within clinician defined limits, based on changes in brain state. A patient's brain state will be measured using a brain signal, such as LFPs, recorded chronically from the implanted electrodes. The goal of the automatic adjustment of therapy may be to maintain the brain state (as defined by these signals) within a clinician specified range (e.g., the range between an upper and lower threshold in the dual threshold mode example), understanding that clinical symptoms and side effects may be well correlated with these detected brain states. In this manner of managing brain states, the user may be able to manage clinical symptoms and side effects. This feature is referred to as closed loop DBS or "aDBS" (adaptive DBS). "cDBS" refers to continuous DBS (i.e. manually controlled and open loop, as in legacy DBS systems).

[0161] In this manner, user interface **400** enables the user to configure adaptive therapy by selecting algorithm, thresholds, and/or stimulation settings for adaptive stimulation modes. In addition to selecting one of the threshold modes, user interface **400** enables the user to configure and adjust one or more thresholds that instruct the system to automatically adapt, or change, stimulation parameter values (e.g., such as shown in FIGS. **13-21**). User interface **400** also enables the user to configure other stimulation settings, changes, limits, transition times, and other settings such as shown in FIGS. **22** and **23**. In some examples, user interface **400** enables the user to view, measure, and assess the performance of the adaptive stimulation using the set thresholds (e.g., as shown in FIGS. **25-32**). User interface **400** may also include other tools to assess stimulation such as tracking events, LFP signals, and stimulation parameters over time.

[0162] In other examples, programmer **104** may provide additional features. For example, programmer **104** may automatically propose a threshold mode (e.g., dual or signal threshold) based on historical timeline data. In some examples, programmer **104** may detect poor or reduced performance based on one or more factures, such as a signal quality check, oscillations in stimulation amplitude of LFP signals, time LFP signals are outside of thresholds exceeds a threshold time, LFP values remain at upper or lower thresholds longer than a predetermined amount of time, the patient turns off stimulation greater than a predetermined number of times or frequency, or any other such events. In some examples, user interface **400** may enable the user to adjust one or more thresholds for stimulation and/or stimulation parameter values while viewing LFP data and/or stimulation parameter values in real-time.

[0163] FIGS. **13-20** are conceptual diagrams illustrating example screens for capturing one or more thresholds associated with adaptive DBS therapy. In this manner, user interface **400** enables a user to define thresholds to quantify changes in a signal over time. These thresholds may be used to summarize large stretches of data to understand patterns of find anomalies worthy of further inspection. FIGS. **13-20** illustrate examples in which user interface **400** enables the user to configure, view, and measure signals against one or more thresholds. For example, a user may set upper and lower thresholds for LFP signals and adjust stimulation amplitude values to put the brain in a state consistent with a desired threshold. User interface **400** may enable the user to manually adjust an LFP threshold and display the thresholds over stored data and/or real-time data. User interface **400** can also show the amount of time the LFP signals are below, between, or above the thresholds.

[0164] In other examples, user interface **400** may display one or more thresholds on the same display as event data or enable the user to set threshold values from timeline, trend, or event data screens. In some examples, user interface **400** may enable the user to adjust non-stimulation threshold settings such as settings related to drug state during stimulation or other patient conditions. User interface **400** may also, or alternatively, show information such as long term averages of LFP values or time below, between, or above thresholds, identification of days or times in which LFP data is a statistical outlier with respect to other data, differences between night and day (or awake and asleep), or other averages or statistics for each stimulation parameter value.

[0165] As shown in the example of FIG. **13**, a representation of a lead and the electrodes carried thereon is displayed in screen **1300**. The cathode and anode electrodes are also indicated to show the selected electrode configuration as part of lead view **1304**. Menu **1302** indicates that lead view **1304** is currently displayed, but that annotation of the electrode configuration can be shown instead. To the right of the lead view **1304**, an LFP graph **1306** and a stimulation parameter graph **1308** are displayed. Capture button **1310** enables the user to request capture of the LFP at the current amplitude. On the very right of the screen **1300** is parameter view **1314** which includes inputs selectable by the user to increase (button **1318**) and decrease (button **1320**) the stimulation parameter, which is current amplitude in the example of FIG. **13**. Button **1316** jumps to the upper amplitude limit that has been set. Button **1322** jumps to the lower amplitude limit when set. Parameter buttons **1324** enable the user to select the desired parameter, such as amplitude, pulse width, or frequency, to adjust. On this screen of FIG. **13**, the user may set parameter value limits that correspond to respective thresholds for the brain signal, such as LFPs. Passive sensing button **1312** causes programmer **104** to save the LFP values for sensing only, instead of adaptive stimulation. The user can move between different screens of user interface **400** via previous button **1210** and next button **1212**.

[0166] Using these screens of user interface **400**, the user can capture thresholds of the LFP that correspond to respective stimulation parameter values. In this manner, the system can determine a LFP Classification threshold using stimulation as the actuator. In one example, each threshold may be set based on measuring LFPs for 25 seconds at particular amplitude levels as defined by the patient's tolerance and symptom relief. Other durations of sensing may be used in other examples.

[0167] Typically, to set the upper threshold and lower threshold for brain signal monitoring, the patient has been off medication, i.e., the upper and lower thresholds are set when the patient is not taking medication selected to reduce the symptoms. The patient may be considered to be not taking the medication when the patient, prior to the time the upper bound is set, has not taken the medication for at least approximately 72 hours for extended release forms of dop-

amine agonists, the patient has not taken the medication for at least approximately 24 hours for regular forms of dopamine agonists and controlled release forms of CD/LD, and the patient has not taken the medication for at least approximately 12 hours for regular forms of CD/LD, entacapone, rasagiline, selegiline, and amantadine. If only stimulation is suppressing brain signals (e.g., LFP signals), then the system can measure these brain signals for various values of stimulation parameters without outside inputs. Once the upper threshold and lower threshold is established, the system can identify when medication wears off because the brain signals will cross the lower or upper threshold. In response to identifying the brain signal crossing a threshold, the system may turn on electrical stimulation to bring back brain signal amplitudes back between the lower threshold and the upper threshold. Thresholds may be set for certain brain signals, such as signals within the Beta frequency band, when the patient is off medication. In some examples, such as when assessing signals within the Gamma frequency band, thresholds may be set when the patient is on medication.

[0168] Since the patient is not getting any medication, LFP activity may be present above a threshold, such as greater than or equal to 1.2 uVp. In this procedure, the user will identify the lowest current amplitude where symptoms are controlled, which will correlate to the upper threshold for the LFP signal. FIG. **14** illustrates an increasing stimulation amplitude with the resulting volume of activation (VOA) shown on the representation of the lead. In the example of FIG. **14**, screen **1400** shows that an increase of stimulation amplitude has caused deliver of stimulation to the patient as indicated by stimulation field **1402**. Slider **1404** may be selected and dragged by the user to increase or decrease the amplitude of stimulation. This lowest amplitude will also be set as the lower limit for the stimulation parameter. FIG. **15** illustrates via screen **1500** that the upper threshold is present and can be captured as upper threshold **1504**. Bubble **1502** informs the user to set the amplitude before capturing the lower LFP threshold. The Beta signal will be high since there is little stimulation amplitude to suppress the brain activity. FIG. **16** shows screen **1600** which includes an example pop-up window **1602** requesting that the patient confirm upper threshold capture at the current amplitude. The system will set the upper threshold here in response to the user selecting the confirm button.

[0169] FIG. **17** illustrates screen **1700** in which the upper threshold **1504** has been captured and the lower limit of current amplitude has been set. Then, the user will increase the current amplitude to highest amplitude at which there are no side effects (or acceptable side effects for the patient in other examples). As shown in FIG. **17**, the current amplitude has been increased to 3.6 mA using slider **1404**, along with the VOA or stimulation field **1402** shown with the representation of the lead **1304**. User selection of the capture button **1310** will capture the sensed LFP amplitude as the lower threshold and set the current amplitude as the upper limit for the amplitude range. FIG. **18** illustrates screen **1800** which includes an example pop-up window **1802** requesting that the patient confirm lower threshold capture at the current amplitude in response to the user selecting the capture button **1310**. The system will set the lower threshold here in response to the user selecting the confirm button. As shown in FIG. **19**, screen **1900** indicates that the upper threshold **1504** has been set and color coordinated to the lower limit for current amplitude (e.g., shown as the same color). The lower threshold **1904** has been set and color coordinated to the upper limit for current amplitude (e.g., shown as the same color different from the upper threshold/lower limit color). In addition to color, the upper threshold **1504** and lower limit has a similar pointing arrow, while the lower threshold **1904** and the upper limit has a similar pointing arrow. In this manner, the system can adjust the current amplitude automatically between the lower and upper limit in order to maintain the LFP signal between the lower and upper thresholds.

[0170] As shown herein, increasing current amplitude (or other stimulation parameters that increase stimulation intensity) may decrease the amplitude of the LFP signal at the selected frequency. Conversely, decreasing current amplitude (or other stimulation parameters that decrease stimulation intensity) may increase the amplitude of the LFP signal at the selected frequency. LFPs below the lower threshold may indicate that the patient is receiving too much stimulation and having dyskinesia, while LFPs above the upper threshold may indicate that the patient's symptoms are not being controlled effectively. In some examples, the average power for the selected frequency over **30** seconds is captured as the upper threshold and the lower threshold. In some examples, processing circuitry **310** may employ error checking on the upper and lower thresholds. For example, processing circuitry **310** may reject capturing a threshold if that capture would result in the upper threshold being below the lower threshold. In addition, or alternatively, processing circuitry may perform a statistical threshold check to ensure that the thresholds are adequately separated from one another.

[0171] As shown in FIG. **19**, the system can capture LFPs during delivery of stimulation. This may be possible because the stimulation electrodes are different from the sensing electrodes. One benefit to this capability of capturing LFPs while delivering stimulation is that the LFP data may be identified when the patient is home so that the system can monitor the LFP thresholds.

[0172] As discussed herein, processing circuitry **310** may obtain a brain signal representative of electrical activity of a brain of a patient, control a medical device (e.g., IMD **106**) to deliver electrical stimulation defined by at least a first value of a stimulation parameter, adjust the first value of the stimulation parameter to a second value of the stimulation parameter at which a patient condition is identified, and determine a threshold value for the brain signal associated with the patient condition. The IMD **106** may be configured to limit automatic adjustment of the stimulation parameter to the second value associated with the threshold value. The threshold value for the brain signal may be associated with one of an upper threshold associated with a therapeutic benefit or a lower threshold for the brain signal associated with a side effect.

[0173] In some examples, processing circuitry **310** may adjust the stimulation parameter to a third value at which a side effect is identified, the third value different than the second value and determine a second threshold value for the brain signal associated with the side effect, the second threshold value associated with a lower threshold. The medical device may be configured to limit automatic adjustment of the stimulation parameter to between the second value and the third value such that the brain signal remains between the upper threshold and the lower threshold. As discussed above, processing circuitry **310** may control a user

interface to display the upper threshold and the lower threshold on a first graph and display the second value and the third value on a second graph. In some examples, the upper threshold and the second value are represented with a first color, and the lower threshold and the third value are represented with a second color different than the first color. As shown in FIG. **19**, processing circuitry **310** may control the user interface to display the threshold value of the brain signal on a first graph, display the second value of the stimulation parameter on a second graph, display a representation of electrodes via which the electrical stimulation is delivered, and display a stimulation field representing the electrical stimulation with respect to the representation of the electrodes. In some examples, user selection of the clear LFP thresholds button **1906** will cause processing circuitry **310** to discard the captured upper and lower threshold.

[0174] FIG. **20** illustrates an example screen **2000** in which user interface **400** indicates a prompt **2002** regarding the amplitude of stimulation. Although the amplitude is within the upper and lower limits, the system may indicate that this stimulation may be too high if adaptive DBS is turned off. Upper limit **2006** is the upper limit of amplitude and lower limit **2004** is the lower limit of amplitude.

[0175] FIG. **21** is a flowchart illustrating an example technique for setting dual thresholds associated with adaptive DBS therapy, which may be done using various screens of user interface **400** described herein. In the example of FIG. **21**, processing circuitry **310** receives user input requesting setting of thresholds for adaptive DBS (**2102**). Processing circuitry **310** captures the upper threshold of the LFP brain signal at the lower limit of stimulation amplitude that reduces symptoms for the patient (**2104**). Processing circuitry **310** then increases stimulation amplitude according to user input (**2106**). Processing circuitry **310** captures the lower threshold of the LFP brain signal at the upper limit of stimulation amplitude that is just below side effects for the patient (**2108**). Processing circuitry **310** then stores the thresholds and limits for adaptive DBS (**2110**). The user may adjust these thresholds and limits manually in some examples.

[0176] FIG. **22** is a conceptual diagram illustrating an example screen **2200** summarizing parameters selected for adaptive DBS therapy. In the example screen **2200** of FIG. **22**, set transitions for moving stimulation up or down are provided along with an indication that the thresholds have been captured. Electrode configuration **2202** shows the electrodes used to sense brain signals. Stimulation settings **2204** indicates the upper limit, lower limit, and suspended amplitude for stimulation therapy. Field **2206** indicates the transition durations when moving between the upper and lower limit of amplitudes, and field **2208** indicates whether the LFP thresholds have been captured or now. User selection of the thresholds edit button for the respective fields **2206** and **2208** will cause processing circuitry **310** to display the screens shown in FIGS. **23** and **24**.

[0177] FIGS. **23** and **24** are conceptual diagrams illustrating example screens for manually adjusting one or more thresholds associated with adaptive DBS therapy. In the example screen **2300** of FIG. **23**, arrow buttons **2306**, **2308**, **2310**, and **2312** are provided to receive user increase or decrease of either the upper threshold **2302** or lower threshold **2304**. The LFP signal is represented by curve **2320**. In this manner, processing circuitry **310** may be configured to receive user input requesting manual adjustment to one or both of the thresholds via user interface **400** and then adjust the respective threshold. FIG. **24** includes example screen **2400** which indicates that the user reduced the upper threshold by **2** steps and increases the lower threshold by **2** steps. User selection of cancel button **2314** will cancel the adjustment to the LFP thresholds. User selection of update button **2316** will cause programmer **104** to change the LFP thresholds as indicated in screen **2400**.

[0178] The system can increase or decrease either threshold. In some examples, the adjustment to the threshold is a relative adjustment to one or both thresholds. For example, the amplitude value separating the upper and lower threshold may be divided into equal steps such that each increase or decrease to the respective threshold causes a normalized change to the threshold. In one example, the magnitude between the thresholds is divided by **100** steps (or some other predetermined number of steps), and each press of the up or down button increases or decreases the threshold by one step. In other examples, each press of the button may change the threshold by a percentage or other relative value for the thresholds.

[0179] FIGS. **25-30** are conceptual diagrams illustrating example screens for displaying sensed brain signals with one or more stimulation parameters defining delivered DBS therapy. FIG. **25** illustrates a screen **2500** in which a selectable "start streaming" button **2510** enables a user to start streaming near-real time brain information, such as LFP Power, and stimulation amplitude simultaneously. Processing circuitry **310** may be configured to display and/or store the streamed LFP information to a memory. Screen **2500** also includes hemisphere selection **2502**, adaptive therapy toggle **2504** to turn adaptive therapy on or off, and menu **2504** which indicates the type of setup screen is current. Adaptive status **2506** indicates what type of stimulation is being delivered. Parameter field **2508** indicates selected amplitude limits, but adaptive stimulation must be suspended before manual parameter value adjustments can be made.

[0180] Once the start streaming button **2510** is selected, processing circuitry **310** begins streaming LFP power information to be displayed in user interface **400**. As shown in FIG. **26**, the screen **2600** of user interface **400** includes two graphs **2602** and **2604**. Each graph displays the LFP power values with respect to the current amplitude value used to deliver stimulation at the same time the LFP power was obtained. The lower graph **2604** may include all data streamed since streaming started. The upper graph **2602** may include the data streamed within a shorter period of time. Box **2606** indicates the period of time from lower graph **2604** from which upper graph **2602** displays the LFP data. In this manner, the lower graph **2604** may cover a larger period of time than the upper graph **2602**, with the lower graph **2604** including the information presented in the upper graph **2602**. In this manner, each graph provides a different time frame for the displayed information. FIG. **27** illustrates screen **2700** in which the graphs **2602** and **2604** will change over time when more data is captured, where the upper graph **2602** maintains a certain time period, and the lower graph time period increases as more data is streamed. As shown, box **2606** decreases in size as more time of LFP data is added to lower graph **2604**.

[0181] The graphs **2602** and **2604** will display any observed changes to the LFP power and the current amplitude. In addition, each graph may include the upper and

lower threshold with the LFP power data and the upper and lower limit with the current amplitude. In this manner, the streaming shown in FIG. **26** enables the user to view how changes to the current amplitude affects the LFP power at the frequency selected for that sensing electrode configuration. In some examples, processing circuitry **310** may automatically calculate the vertical height of the streamed data graph based on threshold and limit values. In other to sense the LFP power while stimulation is delivered, processing circuitry **310** may blank the sensing channel during the time when the stimulation signal is delivered to the patient. Although user interface **400** may prevent the user from adjusting stimulation parameters or thresholds manually via the screen **2600** of FIG. **26**, other examples may provide such ability to manually change one or more thresholds or parameter limits alongside real-time sensing data. In this manner, the clinician can monitor direct changes to LFP power (or another type of brain signal) caused by electrical stimulation and any changes to the electrical stimulation. For example, as shown in FIG. **28**, the screen **2800** provides input buttons (within stimulation field **2508**) that enable the user to change current amplitude while streaming the LFP power data and the stimulation parameter value. FIG. **29** illustrates an example screen **2900** in which adaptive therapy has been suspended as indicated by adaptive therapy toggle **2504**, but a manual limit on current amplitude has been set (**3.3**. mA).

[0182] FIGS. **25** through **29** illustrate example screens for adaptive stimulation. However, the user may switch to passive stimulation as shown in screen **3000** of FIG. **30**. In the screen **3000** of FIG. **30**, LFP power and stimulation amplitude are still displayed. The user can also adjust stimulation amplitude to identify how those adjustments can affect the LFP power. In addition, as shown in FIG. **30**, selection of the patient limits button will cause processing circuitry **310** to present a screen from which the user can adjust the upper or lower limits on current amplitude. The vertical height of each graph may be calculated based on the thresholds and limits.

[0183] As shown in FIGS. **25-30**, user interface **400** provides real time streaming of LFP data on programmer **104**. Once a signal/config has been configured, the system can enable a signal to be streamed in clinic while programming occurs in order to understand the real time response of the signal to stim changes. In this manner, short and long term trends of a selected signal can be displayed, which can be included with stimulation amplitude, adjustment of one or more stimulation parameter values (e.g., amplitude, frequency, and pulse rate). Programmer **104** may store the real time data offline in memory for later analysis and/or review by the user.

[0184] In some examples, user interface **400** may include input mechanisms to receive user input indicative of events or other annotations related to the streaming of data and time of stimulation for the patient. In some examples, user interface **400** may receive input adjusting the time scale of the presented data and/or compare data from different period of times. In other examples, user interface **400** may present real time power spectrum data, multiple signals of interest, or real time analytics. User interface **400** may present information regarding the relative suppression of LFP signal compared to baseline, for example.

[0185] FIGS. **25** through **30** show LFP data streaming from one electrode combination for sensing. In other examples, processing circuitry **310** may store brain signal information (e.g., LFP power) from multiple different electrode combinations. Processing circuitry **310** may then present stored brain signal information from the different electrode combinations together on the same screen to enable the user to identify which electrode combination provides the sensing of brain signals desired by the user.

[0186] FIG. **31** is a flowchart illustrating an example technique for displaying sensed brain signals with one or more stimulation parameters defining delivered DBS therapy, as illustrated in FIGS. **25-30**. As shown in the example of FIG. **31**, processing circuitry **310** may obtain a brain signal representative of electrical activity of a brain of a patient (**3102**). Processing circuitry **310** then obtains one or more values of a stimulation parameter that at least partially defines electrical stimulation deliverable to a portion of the brain of the patient (**3104**). Processing circuitry then outputs, for display by user interface **400**, a graph comprising a first trace of the brain signal for a period of time and a second trace of the one or more values of the stimulation parameter for the period of time (**3106**). The presentation of this information may be in real-time.

[0187] FIGS. **32** and **33** are conceptual diagrams illustrating example screens for adjusting transitions between upper and lower stimulation parameter limits. As shown in FIGS. **32** and **33**, user interface **400** provides screens **3200** and **3300** that enable a user to test aDBS Transition and adjust how the transition occurs. Transition curve **3202** indicates the currently set transition times. Parameter field **3216** provides amplitude limits, current values, and adjustment inputs. Transition up adjustment **3204** represents the current up duration of time, which can be adjusted by moving slider **3212**. Transition down adjustment **3208** represents the current down duration of time, which can be adjusted by moving slider **3214**. Using this transition test, the user can evaluate whether there is an elevated potential for side effects due to rapid transition from stimulation on to off or stimulation off to on. For example, the transition up test button **3206** or the transition down test button **3210** can be selected to initiate simulation of an adaptive therapy transition for all or part of the therapeutic window in the respective direction. Processing circuitry **310** may send the complete command to perform the entire transition up or down to IMD **106** in order to avoid communication delays on each step during the transition. In this manner, IMD **106** will perform the test transition as it would be done automatically by IMD **106** during adaptive DBS.

[0188] Each of the ramps up and down on the top graph, and/or sliders **3212** and **3214** on the timelines below, may be selectable by the user to drag the ramp shorter or longer in time. In one example, processing circuitry **310** can initiate the ramp up or down from any starting amplitude. However, in other examples, processing circuitry **310** may require starting at the lower amplitude and ramping up fully before ramping down fully. Selection of cancel button **3220** cancels any changes to the transition durations. Selection of update button **3222** confirms any changes to the transition durations.

[0189] FIG. **34** is a conceptual diagram illustrating an example home screen **3402** of user interface **400** for navigating to view stored patient event data, which may be similar to screen **402**. When the user selects event button **3404** on the menu screen **3402**, user interface **400** expands the event button and displays a confirmation button **3406**

that must be selected by the user before processing circuitry **310** moves to the event set of screens shown in FIGS. **35-42**.

[0190] FIGS. **35-42** are conceptual diagrams illustrating example screens for displaying patient event data arranged by user selectable times. FIGS. **35-39** illustrate example screens that show a number of each type of events that occurred during one or more periods of time. FIG. **35** illustrates an example screen **3500** in which four different events are shown for two different period of time (e.g., respective weeks of time) in table **3508**. The example events include "took medication," "fell," "dyskinesia," and "on time." These events may be patient events that are indicated by the patient when they occur, such as the took medication, fell, dyskinesia events, and "on time." The "on time" may be the number of times in which the patient felt well and symptoms have been reduced or eliminated. The timing and number of each event may help a clinician evaluate the efficacy of stimulation therapy for the patient. Menu **3502** indicates which type of information is being displayed, which indicates that the summary is displayed in screen **3500**. View selection **3504** indicates the time frame for each column of data (e.g., day, week, month, hours, etc.). Range selector **3506** indicates which data will be used to populate table **3508**. Event selector **3510** can be selected so that the user can select which type of events are shown in table **3508**. The user can read all events by selecting button **3512** or close screen **3500** by selecting close button **3514**.

[0191] FIG. **36** illustrates screen **3600** which includes a drop down menu for view selector **3504** from which the user can select different periods of time for which the events can be parsed. FIG. **37** illustrates screen **3700** which includes a drop down menu for range selector **3506** from which the user can select which data to use in the chart. FIG. **38** includes an example screen **3800** in which the events are shown for each day in table **3808**. FIG. **39** includes an example screen **3900** in which the events are shown since the last session with the clinician in table **3908**.

[0192] FIG. **40** illustrates an example screen **4000** that displays LFP classifications determined by processing circuitry **310** in chart **4008**. Processing circuitry **310** may classify brain state over user selectable ranges and bins based upon measured thresholds. For example, the chart **4008** of FIG. **40** includes classification of amount of time the LFP amplitude was above the upper threshold, the amount of time the LFP amplitude was below the lower threshold, and the amount of time the LFP amplitude was between the upper and lower thresholds. This amount of time is shown in percentage of time, but could be displayed minutes, hours, or other absolute measurement of time. Using these indications, a clinician can view how effective stimulation has been in keeping the LFP amplitude between the upper and lower thresholds. This may be an objective measure of efficacy of adaptive DBS.

[0193] In addition, the chart **4008** of FIG. **40** illustrates the average amplitude of the stimulation parameter during stimulation and the adaptive amplitude reduction metric to show how adaptive therapy is impacting the amount of stimulation the patient is receiving. When adaptive therapy is running, processing circuitry **310** may calculate and display the average reduction in amplitude between the adaptive amplitude and the continuous stimulation default amplitude value. Higher percentages indicate that adaptive DBS is reducing the amount of stimulation that is delivered and thus reducing the power consumption of the battery of the IMD **106**. The chart **4008** may also include the amount of time the adaptive DBS was running for the period of time indicated in the chart.

[0194] In some examples, the chart **4008** of FIG. **40** may flag incomplete or otherwise bad data or indicate trends in therapy or sensing over the different time periods. FIG. **41** shows a screen **4100** that includes two different weeks and corresponding LFP classifications in example chart **4108**.

[0195] FIG. **42** presents a screen **4200** in which the user can specify which patient events can be indicated by the patient and whether or not LFP data should be captured in response to the user indicating that the patient event occurred. Screen **4200** may be entered by selecting configure event selector **3510** from screen **4100**, for example. The user can select the appropriate one of boxes **4202** to select which one or more of events **4202** to include in the displayed data. For each of the events, LFP capture **4206** indicates whether LFPs were captured for that event or whether stimulation cycling **4208** was used for that event. Selection of cancel button **4210** will not save any changes to the patient events, but selection of update button **4212** will cause programmer **104** to change how patient events are shows as selected. In some examples, the language of patient programmer user interface can be different than the physician programmer language. A medical translator could enter events, group names, or other information in the language of the patient for the patient programmer, while the clinician programmer can maintain the language used by the clinician.

[0196] User interface **400** can present information related to patient events in numerous different ways. As described herein, once a sensing electrical combination has been configured and used for sensing, the system allows a patient or other user to mark an event contemporaneously or after its occurrence. Programmer **104** may control IMD **106** to capture a signature of the sensed brain signal after that event (and prior to the event by using a sensing buffer that temporarily stores brain signals). Programmer **104** may control user interface **400** to presenting one event with other similar or different events. In this manner, user interface **400** can help a user understand real world response of brain states to medications, stimulation, and other daily activities to inform future therapy management which can include available stimulation parameter values and/or improvements to closed-loop control of stimulation. Example screens of user interface **400** that can provide this information are included in FIGS. **42-47**.

[0197] User interface **400** can provide various structure and functionality for presenting patient events. For example, user interface **400** can accept input naming different event types, selection of one or more actions (e.g., recording data and/or stimulation adjustments) that should occur in response to detection of a particular patient event or event type, request for a comparison view of multiple events or event types, input requesting analysis of the data such as the frequency of events, number of events, or severity of events, or any other type of input. In addition, user interface **400** may enable a user to filter (e.g., add or remove) events, event types, time periods, or other information to customize the view of stored information.

[0198] In some examples, programmer **104** may perform statistical analyses on various data within or between events. For example, programmer **104** may determine an average peak frequency for different events or type of events, average peak magnitudes for different events or types of events,

correlations of events to different LFP data, etc. Programmer **104** may also cluster events together based on the similarity of one or more characteristics of the sensed brain signal sensed during the events. For example, programmer **104** may cluster events together that have a peak at a similar frequency in the beta band and that these events occur at a similar time of day (e.g., in the morning on weekdays) or have other similarities such as similar accelerometer data. Programmer **104** may then control user interface **400** to present these statistical conclusions, clustered events, etc.

[0199] FIGS. **43-47** are conceptual diagrams illustrating example screens for displaying brain signal graphs for respective patient events. The brain signal information (e.g., spectral information for a brain signal) can be obtained by IMD **106** in response to the user providing input indicating that a patient event occurred. IMD **106** may capture Beta and/or Gamma band data for each event. The clinician can determine which bands or frequencies are good biomarkers for that type of event that happened based on the captured brain signal information for that event. This functionality may also be beneficial for the patient since medication takes a long time to wear off and may not occur during a clinic visit.

[0200] In response to the user pressing a button on the patient programmer or clinician programmer, the programmer may control IMD **106** to capture LFP information for a period of time (e.g., **25** seconds). This LFP information may be sensed after the event has been indicated. However, in other examples, IMD **106** may maintain a rolling buffer and capture LFP information before, during, and after the event was indicated to occur. In other examples when LFP data is stored for long periods of time, the user may be able to go back and mark an event that occurred hours or days before, and the system may capture the LFP information recorded at the time of the indicated event. The LFP information captured may include time domain information and/or an FFT transform of recorded LFP data. In some examples, processing circuitry **310** may select a certain number of power values across the frequency domain, such as **100** power values. However, more or less data may be stored for each sample of LFP information in other examples. The LFP data may be stored on the patient programmer or IMD **106**. In other examples, the LFP information may be transmitted to the cloud or other device for storage. In some examples, the LFP information may be directly transmitted to a clinician.

[0201] FIG. **43** illustrates a screen **4300** showing patient events and corresponding LFP information displayed on a graph **4306** of LFP power vs. frequency. Traces **4312** are the LFP powers for each event shown in event list **4314**. Hemisphere selector **4302** can be selected to switch between signals sensed from different leads, and range selector **4304** can be selected to switch between different dates for sensed data. Although four event types are shown as selectable in this example (from FIG. **42**), fewer or greater types of events may be indicated by the user in other examples. The screen **4300** of FIG. **43** provides a slider **4310** that the user can move to adjust frequency bar **4308** and identify the frequency and/or power of any part of each trace. On the right of the screen **4300**, the event list **4314** of each event is provided. In response to the user deselecting an event (e.g., by unchecking the respective check box), user interface **400** will remove that specific trace for that event from the graph **4306**. In this manner, the user can choose to evaluate any events and compare any events. In other examples, other types of information could be captured for each event, such as medication status, accelerometer data, stimulation delivery status, etc. Each of these types of information may be presented on the same graph or different graphs for each type of information. Selection of close button **4318** will close screen **4300**.

[0202] FIG. **44** shows a pop up window **4400** that is shown in response to selection of filter button **4316** in screen **4300**. In pop up window **4400**, the user can select the type of event to show on the screen. The types of event **4404** are shown and can be selected or unselected via the respective check box **4402**. Selection of cancel button **4210** will cancel the changes and selection of update button **4212** will change the event types shown in the next screen. FIG. **45** includes screen **4500** which indicates a took medication event and corresponding LFP trace **4504** in graph **4502** selected by the user from the window **4400** of FIG. **44**. FIG. **46** illustrates an example screen **4600** in which a dyskinesia event was identified and the corresponding trace **4604** is shown in graph **4602**. In some examples, programmer **104** may automatically place frequency bar **4308** at the peak in frequency, but the user can always move slider **4310** to the peak on trace **4604**. FIG. **47** illustrates an example screen **4700** in which fall events (e.g., all events within the fall event type) were identified and the corresponding LFP data are shown as traces **4704** in graph **4702**.

[0203] FIG. **48** is a flowchart illustrating an example technique for generating and displaying brain signal graphs for respective patient events, such as the screens of FIGS. **42-47**. In the example of FIG. **48**, processing circuitry **310** receives an indication of an event at a time (**4802**) and, responsive to receiving the indication of the event, stores spectral information for a brain signal recorded at the time (**4804**). In some examples, the stored spectral information may have been obtained only after receiving the indication of the event. In other examples, processing circuitry **310** may retrieve spectral information obtained prior to the event from a buffer in memory. Processing circuitry **310** then outputs, for display by a user interface, a graph indicating the spectral information for the brain signal recorded at the time (**4806**). Processing circuitry **310** can then control user interface **400** to adjust the displayed events and corresponding traces or other information in response to user requests.

[0204] FIG. **49** is a conceptual diagram illustrating an example screen **4900** for displaying amounts of time a brain signal characteristic is within a respective range of brain signal values. As shown in FIG. **49**, screen **4900** shows bar graphs **4904** of the amount of time the brain signal (e.g., LFP power) is above an upper threshold, below a lower threshold, and between the upper and lower thresholds. This information can be viewed for different periods of time, such as by day, week, or month. Selection of the period of time can be made via time selection **4908**, which may be a drop down menu. Data selector **4902** can enable a user to select the type of data, such as type of stimulation delivered or group of data that was stored. Arrows **4906** can be selected to move to different days or to view data for other time periods that do not fit within the graph.

[0205] FIGS. **50-55** are conceptual diagrams illustrating example screens for displaying a graph of brain signal characteristics and stimulation parameter values from DBS therapy over time. This information may be stored over time and similar to an electronic motor diary. Stored information may include brain signal information (e.g., LFP power),

stimulation parameter values, patient events, and/or system events. This type of information may allow a clinician to review stored brain signal information over time that was collected outside of the clinical setting.

[0206] Once a sensing electrode combination has been configured, the system can record the sensed signal continuously (e.g., in memory of IMD **106** and or until offloaded to programmer **104** or another device). Programmer **104** than controls user interface **400** to display the data for review at a clinical or follow up visit, for example. The goal of presenting this data may be to help a user understand real world response of brain state to medications, stimulation, and other daily activities to inform future therapy management. In some examples, the display may show trends of the stored LFP signal, trends of the stimulation parameter values (such as amplitude), any events sensed or marked by the patient during that time, one or more stimulation parameter values used to deliver stimulation during this time, one or more hemispheres (e.g., one or two leads), LFP thresholds, stimulation limits, or any other information related to stored data.

[0207] In some examples, user interface **400** may enable the user to reduce or increase the time period of displayed data (e.g., change from showing minutes, hours, days, weeks, or months). In some examples, programmer **104** may control user interface **400** may identify days with similar events or stored data, cluster days or other time periods together, or determine statistical measures. Example statistical measures may include an average day, an average night, trends observed before and/or after an event, observed trends before and/or after a stimulation parameter value change, or comparisons between different stimulation programs.

[0208] In the example screen **5000** of FIG. **50**, LFP power over time is shown as a trace **5006** of a graph in conjunction with a trace **5016** of current amplitude over the same time for one lead in one hemisphere of the patient. Although the upper limit **5020** and lower limit **5018** of the stimulation parameter are shown in the graph, the limits or thresholds may not be presented in other examples. Upper and/or lower thresholds for LFP data may also be shown. Screen **5000** in FIG. **50** also indicates patient event **5012** (e.g., a patient marked event) and system event **5014** (e.g., a parameter value change) that were identified and displays them at the time at which they were identified. The patient event **5012** and system event **5014** may be identified using different colors. User selection of patient event **5012** or system event **5014** may open a window that includes additional information related to that event, such as more specific LFP data or what parameter value changes were made. Using this timeline, the clinician can view historical brain signal information, stimulation information, and event information on the same graph. The timeline **5004** above the graph indicates days of the month. Therefore, the graph of FIG. **50** can present data for an entire month in one screen. In other examples, the timeline may be shrunk to weeks or days or expanded to multiple months or years. Time selector **5002** may be selected to choose a different period of time to show data. Each LFP and stimulation data point may be sampled at a certain rate, such as six times per hour. However, higher or lower sample rates may be used depending on data storage capabilities and types of graph to be presented.

[0209] FIG. **51** includes screen **5100** that indicates that selecting of the patient event causes processing circuitry **310** to present a snapshot **5102** of the LFP spectral information stored at the same time of the patient event. A clinician can then identify if anything unusual occurred during that event or identify a certain frequency of the brain signal that may be useful for preventing, or encouraging, that patient event in the future. The "on time" flag for this patient event indicates the patient felt good at this time.

[0210] FIG. **52** illustrates a screen **5200** in which system events, which include changes to stimulation parameters, are marked in the data. The system events **5202** and **5204** show stopping and starting stimulation. As can be seen in FIG. **52**, stimulation was turned on in response to detecting that the LFP power exceeded the upper threshold. Patient event **5206** is also shown in the graph. As shown in screen **5300** of FIG. **53**, the user can click on either of the system events **5202** or **5204** to expand the event to show what event occurred. As shown in the window **5302**, the system event was that stimulation was turned off at that particular time of day listed. FIG. **54** illustrates a screen **5400** in which a patient event **5404** was marked when the LFP power was below the lower threshold, likely due to side effects from stimulation. Marker identifiers **5402** indicate which days of the month had events recorded, and which type of events (patient events or system events) were recorded via color coding. FIG. **55** illustrates a screen **5500** in which LFP power and stimulation parameter values for both hemispheres of the brain are shown together. The stimulation parameter could be the same or different for each hemisphere. Although brain signals typically move together, diverging signals from separate hemispheres may indicate another issue for the patient. Patient event **5506** is shown in conjunction with.

[0211] As shown in FIG. **55**, the graph can present a full day worth of objective LFP information and correlated stimulation parameter data on the same screen. In addition, the same screen may show stimulation changes and patient-reported events such as feeling well, feeling side effects, taking medication, etc. in some examples, all data is stored on the programmer, so no network connection is required to present this information. However, in other examples, the programmer may send data to, for viewing on, a digital health platform for the clinician. In some examples, the screens of FIGS. **50-55** may enable a user to filter events by type of event, LFP power ranges, stimulation events, threshold crossings, etc.

[0212] FIG. **56** is a flowchart illustrating an example technique for generating and displaying a graph of brain signal characteristics and stimulation parameter values from DBS therapy over time. The process of FIG. **56** may correspond to the user interface **400** described with respect to and of FIGS. **50-55**. FIG. **56** is a flowchart illustrating an example technique for displaying sensed brain signals with one or more stimulation parameters defining delivered DBS therapy from historical data. As shown in FIG. **56**, processing circuitry **310** may obtain a brain signal representative of electrical activity of a brain of a patient for a period of time (**5602**). Processing circuitry **310** then obtains stimulation parameter information that at least partially defines electrical stimulation deliverable to a portion of the brain of the patient during the period of time (**5604**). Processing circuitry **310** then outputs, for display by user interface **400**, a graph comprising a first trace of the brain signal for a period of time and a second trace of the one or more values of the stimulation parameter information for the period of time (**5606**).

[0213] FIG. **57** is a conceptual diagram illustrating an example screen **5700** for displaying an amount of time different types of DBS therapy were delivered for respective dates. As shown in FIG. **57**, user interface **400** may display device usage for each type of stimulation program in bar graph **5702**, such as adaptive stimulation or talking. This information can be viewed by different periods of time, such as day, week, or month, which can be selected via time selector **5706**. Key **5704** indicates the types of therapy that was used as shown in bar graph **5702**.

[0214] FIGS. **58** and **59** are conceptual diagrams illustrating example screens **5800** and **5900** for displaying graphs of brain signal power for respective electrode combinations of a lead. The graph of screen **5800** of FIG. **58** may include LFP information **5808** (e.g., traces) recorded for each electrode combination (channel) available. Typically, the best electrode combinations are those with peaks present at a certain frequency as shown in the LFP power vs. frequency graph. This screen **5800** enables the user to select different sense channels **5802** to highlight the corresponding trace for that channel within the group of all traces for all channels. In screen **5800**, the user has selected sense channel **5804**, and lead **5812** shows the electrodes of the lead used for this particular sense channel. LFP information **5808** shows all of the traces for the sense channels **5802**. Trace **5810** may be highlighted (e.g., using a thicker line, dotted line, different color, etc.) and indicates the LFP data saved for selected sense channel **5804**. The user can select refresh brainsense survey **5804** to cause programmer **104** to initiate new sensing of LFP information for all of sense channels **5802**. FIG. **59** includes screen **5900** which illustrates that the user has selected sense channel **5904** (e.g., electrodes "**0** to **2**") which corresponds to the trace **5910** with the highest peak in the Beta frequency band for all of LFP information **5808**. Lead **5812** provides a visual indication of the electrodes used for sense channel **5904**.

[0215] As discussed herein, programmer **104** may initiate an automatic scan of brain signals from all or most sense channels available to enable programmer **104** or a user to identify where signals might be located (which hemisphere, which region of a lead, which specific combinations of contacts) for the purpose of understanding such signals, the integrity or quality of the recording system, and then guiding sensing configuration and/or stimulation parameters values. Screen **5800** of FIG. **58** shows a specific list of contacts to be scanned, and programmer **104** may use the finite sensing resources of IMD **106** to capture all signals "close" to synchronously so that they can be compared directly on relative scales. Once the LFP data are captured during scanning, programmer **104** ma calculate a power spectrum for each sensing channel and control user interface **400** to creates an interactive display of this LFP data.

[0216] In this manner, user interface **400** can provide a view of all signals in a hemisphere simultaneously and enable selection of one signal to be compared to the others. Programmer **104** may measure aspects of the signal (e.g., difference between maximum and/or minimum at a specific frequency of interest). Programmer **104** may enable IMD **106** to continuously record a subset of signals. In some examples, programmer **104** may perform statistical comparisons (e.g., an energy in a region of frequencies compared to the energy at a specific peak, the relative amplitude above 1/frequency of the curve, the width of the peak, or simultaneous comparison or measurement of two or more peaks. In some examples, user interface **400** may provide additional views for leads having electrodes at different locations around a perimeter of a lead (e.g., directional leads). User interface **400** may also provide visualization of anatomic structures or other reference in combination with a signal location (e.g., whether or not a signal is in or out of target, or if a signal is medial or lateral from an anatomical structure).

[0217] FIGS. **60-69** are conceptual diagrams illustrating example screens of a user interface for a patient programmer associated with entering an MRI mode for a medical device. FIG. **60** illustrates a screen **6002** that includes a navigation menu **6004** from which the user can enter the "MRI mode" by selecting MRI mode button **6006**. This mode is used to check the MRI eligibility for IMD **106** implanted within the patient and enable the patient to directly enter the MRI mode if eligible, using the patient programmer. Upon selecting the "MRI mode" button **6006** in FIG. **60**, the user interface presents FIG. **61** in which screen **6100** prompts the user to continue into MRI mode using continue button **6102**. Home button **6104** can be selected to leave the MRI mode process. FIG. **62** includes a screen **6200** to prompt the use to select the device to be checked. Button **6202** indicates a device located in the body (such as the left chest), and button **6204** indicates a device located in the head. Back button **6206** takes the user back to the previous screen **6100**, and continue button **6208** moves to the next screen in the process. The screen **6300** of FIG. **63** enables the user to turn therapy off directly from the MRI eligibility check without navigating to different screens via therapy off button **6302**. If the user selects to turn off therapy, the user interface prompts the user to confirm that the therapy should be turned off in screen **6400** of FIG. **64**. For example, pop up window **6402** includes a therapy off button **6404** which must be selected to turn off therapy. Selection of cancel button **6406** returns to the previous screen and therapy remains on.

[0218] FIG. **65** includes a screen **6500** in which the user is prompted to turn any other devices into MRI mode as well. Upon selecting continue button **6502**, screen **6600** of FIG. **66** is shown and prompts the user to start the MRI eligibility check by selecting start test button **6602**. Selecting back button **6604** returns to a previous screen. Responsive to receiving selection of the "start test" button **6602**, the user interface moves to the screen **6700** in FIG. **67** that indicates the status of the MRI eligibility test via status bar **6702** (e.g., showing a percentage of the process). From this screen, the user can select to stop the test if desired via stop test button **6704**. If the test is successful, FIG. **68** indicates that the programmer has put the one or more neurostimulators into MRI mode. In pop up window **6802** of screen **6800**, the user can select OK button **6904** to proceed in MRI mode. Once in MRI mode, screen **6900** of FIG. **69** indicates that the user interface will present a button **6904** that, when pressed, will cause the programmer to control the implanted devices to exit the MRI mode. Button **6902** can toggle between different devices in different locations of the patient.

[0219] FIGS. **70-75** are conceptual diagrams illustrating example screens of a user interface associated with entering an MRI mode for a medical device. In the examples of FIGS. **70-75**, the clinician programmer may enter an MRI mode for stimulation devices. FIG. **70** illustrates a screen **7002** where the clinician can confirm system components and any other eligibility factors for MRI eligibility. Stimulation toggle **7004** enables a user to turn stimulation on or off. Menu **7014**

provides the different screens in which information related to the device can be viewed. Components button **7006** can show the user additional components associated with the patient, and button **7008** can show additional factors related to MRI eligibility. Cancel button **7010** will cancel this portion of the MRI check. Selection of confirm button **7012** will confirm that MRI test can proceed. FIG. **71** illustrates a screen **7100** showing the system eligibility for each component of the system. The screen **7200** of FIG. **72** is configured to receive user input turning stimulation off or on for MRI imaging. In addition, FIG. **72** provides an enter MRI mode button **7204** that, when selected, causes the programmer to place the IMD into the MRI mode. Report button **7202** will cause user interface **400** to present a report regarding the MRI eligibility for the patient. FIG. **73** includes screen **7300** which indicates a pop-up screen **7302** in which the user can confirm that the system should enter the therapy mode eligible for MRI scans by selecting OK button **7306**. Cancel button **7304** will cancel the MRI setting. FIG. **74** provides a screen **7400** that indicates that the IMD is in MRI mode. Report button **7402** will cause user interface **400** to present a report regarding the MRI mode for the patient. Programmer **106** will control the IMD to exit the MRI mode in response to the user selecting the exit MRI mode button **7404**.

[0220] FIG. **75** is a flowchart illustrating an example technique for managing the sensing of brain signals. As shown in the example flowchart of FIG. **75**, LFP power can be recorded and presented to a user in order to adjust settings for therapy that is not automatically adjusted. For example, processing circuitry **310** of programmer **104** may determine a sensing electrode configuration from monopolar review of electrode combinations (**7502**). Processing circuitry **310** then determines the therapeutic window for stimulation (**7504**). This process may be automated or performed with input from a user. Processing circuitry **310** then analyzes LFP energy sensed on the different sensing channels (**7506**).

[0221] Based on the LFP energy, processing circuitry **310** determines values for stimulation parameters and/or other feedback, such as feedback from the patient or clinician (**7508**). Processing circuitry **310** then controls IMD **106** to deliver therapy using these stimulation parameter values (**7510**). If there is no patient or clinician feedback ("No" branch of block **7512**), processing circuitry **310** continues to analyze LFP energy and adjust stimulation parameter values as need to adapt stimulation to changing brain states (**7506**). This automated process for referring the LFP signals enables adaptive stimulation for the patient. If processing circuitry **310** determines that there is patient or clinician feedback ("YES" branch of block **7512**), processing circuitry **310** analyzes the feedback for any adjustments to make to one or more stimulation parameters (**7514**). For example, feedback indicating that the patient experiences dyskinesia at some times may cause processing circuitry **310** to reduce the upper limit of stimulation amplitude.

[0222] FIG. **76** is a flowchart illustrating an example technique for setting up and managing adaptive stimulation using brain signals. As shown in the example flowchart of FIG. **76**, an IMD can employ LFP power to automatically adjust one or more stimulation parameters in order to maintain the LFP power at appropriate levels with respect to one or more thresholds. For example, processing circuitry **310** of programmer **104** may determine a sensing electrode configuration from monopolar review of electrode combinations (**7602**). Processing circuitry **310** then determines the therapeutic window for stimulation (**7604**). This process may be automated or performed with input from a user. Processing circuitry **310** then analyzes LFP energy sensed on the different sensing channels (**7606**).

[0223] Based on the LFP energy, processing circuitry **310** determines values for stimulation parameters and/or other feedback, such as feedback from the patient or clinician (**7608**). Processing circuitry **310** then controls IMD **106** to deliver therapy using these stimulation parameter values (**7610**). If there is no clinician adjustment made during an office visit or other clinician intervention ("No" branch of block **7612**), processing circuitry **310** continues to analyze LFP energy and adjust stimulation parameter values as need to adapt stimulation to changing brain states (**7606**). This automated process for referring the LFP signals enables adaptive stimulation for the patient. If processing circuitry **310** determines that there is clinician adjustment ("YES" branch of block **7612**), processing circuitry **310** analyzes the feedback for any adjustments to make to one or more stimulation parameters (**7614**). For example, the clinician may review data and request an adjustment to LFP thresholds and/or stimulation limits.

[0224] The following examples are described herein. Example 1. A method comprising: obtaining, by processing circuitry, brain signal information for at least one electrode combination of a plurality of electrode combinations of one or more electrical leads; determining, by the processing circuitry and based on the brain signal information, a respective frequency for the at least one electrode combination; outputting, for display, a plurality of selectable lead icons, wherein each selectable lead icon of the plurality of selectable lead icons represents a different electrode combination of the plurality of electrode combinations; outputting, for display, the respective frequency determined for the at least one electrode combination in association with the respective selectable lead icon associated with the at least one electrode combination; receiving user input selecting one selectable lead icon of the plurality of selectable lead icons; and responsive to receiving the user input, selecting, by the processing circuitry and for subsequent brain signal sensing, a sense electrode combination associated with the one selectable lead icon selected by the user input.

[0225] Example 2. The method of example 1, further comprising: outputting, for display, a selectable signal test icon; receiving user input selecting the selectable signal test icon; and responsive to receiving the user input selecting the selectable signal test icon, controlling a medical device to obtain brain signal information for at least one electrode combination of the plurality of electrode combinations.

[0226] Example 3. The method of any of examples 1 though 2, wherein the plurality of electrode combinations comprises all electrode combinations possible for the one or more electrical leads implanted within a patient.

[0227] Example 4. The method of any of examples 1 though 3, further comprising: analyzing the brain signal information for presence of an artifact associated with at least one of electrocardiogram sensing or motion of the one or more electrical leads; determining that the artifact is not present in the brain signal information; and responsive to determining that the artifact is not present, approving the one or more electrode combinations for selection by a user for subsequent brain signal sensing.

[0228] Example 5. The method of example 4, wherein analyzing the brain signal information for presence of the artifact comprises applying a logistic regression classifier to at least a portion of the brain signal information.

[0229] Example 6. The method of example 5, further comprising determining a plurality of signal features from the brain signal information, the plurality of signal features comprise entropies for a plurality of frequency bands within the brain signal information and a plurality of time domain threshold crossing features, wherein applying the logistic regression classifier to the portion of the brain signal information comprises applying the logistic regression classifier to the plurality of signal features.

[0230] Example 7. The method of any of examples 4 though 6, wherein analyzing the brain signal information for presence of the artifact associated with the electrocardiogram comprises analyzing the brain signal information for a fast Fourier transform (FFT) amplitude separation at approximately 8 Hz between a first brain signal detected during delivery of electrical stimulation and a second brain signal detecting during an absence of electrical stimulation delivery; and wherein the FFT amplitude separation less than a separation threshold indicates that the artifact is not present.

[0231] Example 8. The method of any of examples 1 though 7, wherein the brain signal information comprises one or more local field potential signals.

[0232] Example 9. The method of any of examples 1 though 8, wherein an external programmer comprises the processing circuitry, the external programmer configured to control an implantable medical device configured to be coupled to the one or more electrical leads.

[0233] Example 10. An external programmer comprising: processing circuitry configured to: obtain brain signal information for at least one electrode combination of a plurality of electrode combinations of one or more electrical leads; determine, based on the brain signal information, a respective frequency for the at least one electrode combination; output, for display, a plurality of selectable lead icons, wherein each selectable lead icon of the plurality of selectable lead icons represents a different electrode combination of the plurality of electrode combinations; output, for display, the respective frequency determined for the at least one electrode combination in association with the respective selectable lead icon associated with the at least one electrode combination; receive user input selecting one selectable lead icon of the plurality of selectable lead icons; and responsive to receiving the user input, selecting, for subsequent brain signal sensing, a sense electrode combination associated with the one selectable lead icon selected by the user input.

[0234] Example 11. The external programmer of example 10, wherein the processing circuitry is further configured to: output, for display, a selectable signal test icon; receive user input selecting the selectable signal test icon; and responsive to receiving the user input selecting the selectable signal test icon, control a medical device to obtain brain signal information for at least one electrode combination of the plurality of electrode combinations.

[0235] Example 12. The external programmer of any of examples 10 though 11, wherein the plurality of electrode combinations comprises all electrode combinations possible for the one or more electrical leads implanted within a patient.

[0236] Example 13. The external programmer of any of examples 10 though 12, wherein the processing circuitry is further configured to: analyze the brain signal information for presence of an artifact associated with at least one of electrocardiogram sensing or motion of the one or more electrical leads; determine that the artifact is not present in the brain signal information; and responsive to determining that the artifact is not present, approve the one or more electrode combinations for selection by a user for subsequent brain signal sensing.

[0237] Example 14. The external programmer of example 13, wherein the processing circuitry is configured to analyze the brain signal information for presence of the artifact by at least applying a logistic regression classifier to at least a portion of the brain signal information.

[0238] Example 15. The external programmer of example 14, wherein the processing circuitry is further configured to determine a plurality of signal features from the brain signal information, the plurality of signal features comprise entropies for a plurality of frequency bands within the brain signal information and a plurality of time domain threshold crossing features, wherein the processing circuitry is configured to apply the logistic regression classifier to the portion of the brain signal information by at least applying the logistic regression classifier to the plurality of signal features.

[0239] Example 16. The external programmer of any of examples 13 though 15, wherein the processing circuitry is configured to analyze the brain signal information for presence of the artifact associated with the electrocardiogram by at least analyzing the brain signal information for a fast Fourier transform (FFT) amplitude separation at approximately 8 Hz between a first brain signal detected during delivery of electrical stimulation and a second brain signal detecting during an absence of electrical stimulation delivery; and wherein the FFT amplitude separation less than a separation threshold indicates that the artifact is not present.

[0240] Example 17. The external programmer of any of examples 10 though 16, wherein the brain signal information comprises one or more local field potential signals.

[0241] Example 18. The external programmer of any of examples 1 though 17, wherein the external programmer is configured to control an implantable medical device configured to be coupled to the one or more electrical leads.

[0242] Example 19. An external programmer comprising means for performing the method of any of examples 1 though 9.

[0243] Example 20. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to obtain brain signal information for at least one electrode combination of a plurality of electrode combinations of one or more electrical leads; determine, based on the brain signal information, a respective frequency for the at least one electrode combination; output, for display, a plurality of selectable lead icons, wherein each selectable lead icon of the plurality of selectable lead icons represents a different electrode combination of the plurality of electrode combinations; output, for display, the respective frequency determined for the at least one electrode combination in association with the respective selectable lead icon associated with the at least one electrode combination; receive user input selecting one selectable lead icon of the plurality of selectable lead icons; and responsive to receiving the user input, selecting, for subsequent brain

signal sensing, a sense electrode combination associated with the one selectable lead icon selected by the user input.

[0244] Example 21. A method comprising: obtaining, by processing circuitry, a brain signal representative of electrical activity of a brain of a patient; controlling, by the processing circuitry, a medical device to deliver electrical stimulation defined by at least a first value of a stimulation parameter; adjusting, by the processing circuitry, the first value of the stimulation parameter to a second value of the stimulation parameter at which a patient condition is identified; and determining, by the processing circuitry, a threshold value for the brain signal associated with the patient condition, wherein the medical device is configured to limit automatic adjustment of the stimulation parameter to the second value associated with the threshold value.

[0245] Example 22. The method of example 21, wherein the threshold value for the brain signal is associated with one of an upper threshold associated with a therapeutic benefit or a lower threshold for the brain signal associated with a side effect.

[0246] Example 23. The method of any of examples 21 and 22, wherein the patient condition comprises a therapeutic benefit and the threshold value comprises a first threshold value associated with an upper threshold, further comprising: adjusting the stimulation parameter to a third value at which a side effect is identified, the third value different than the second value; and determining a second threshold value for the brain signal associated with the side effect, the second threshold value associated with a lower threshold, wherein the medical device is configured to limit automatic adjustment of the stimulation parameter to between the second value and the third value such that the brain signal remains between the upper threshold and the lower threshold.

[0247] Example 24. The method of any of examples 21 though 23, further comprising controlling a user interface to: display the upper threshold and the lower threshold on a first graph; and display the second value and the third value on a second graph.

[0248] Example 25. The method of example 24, wherein the upper threshold and the second value are represented with a first color, and wherein the lower threshold and the third value are represented with a second color different than the first color.

[0249] Example 26. The method of any of examples 21 though 25, wherein adjusting the first value of the stimulation parameter to the second value of the stimulation parameter comprises: receiving, via a user interface, user input requesting an adjustment from the first value to the second value; and responsive to receiving the user input, adjusting the first value to the second value.

[0250] Example 27. The method of any of examples 21 though 26, wherein determining the threshold value for the brain signal comprises: receiving, via a user interface, user input requesting capture of the threshold value; and identifying the threshold value of the brain signal corresponding to an amplitude value of the brain signal obtained at a time the user input was received.

[0251] Example 28. The method of any of examples 21 though 27, wherein the threshold value comprises a first threshold value, wherein the method further comprising: receiving, via a user interface, user input requesting a manual adjustment to the first threshold value; and adjusting the first threshold value to a second threshold value according to the user input.

[0252] Example 29. The method of any of examples 21 though 28, further comprising controlling a user interface to: display the threshold value of the brain signal on a first graph; display the second value of the stimulation parameter on a second graph; display a representation of electrodes via which the electrical stimulation is delivered; and display a stimulation field representing the electrical stimulation with respect to the representation of the electrodes.

[0253] Example 30. The method of any of examples 21 though 29, wherein the brain signal comprises one or more local field potential signals.

[0254] Example 31. The method of any of examples 21 though 30, wherein an external programmer comprises the processing circuitry, the external programmer configured to control the medical device configured to be coupled to the one or more electrical leads.

[0255] Example 32. An external programmer configured to perform the method of any of examples 21 though 31.

[0256] Example 33. An external programmer comprising means for performing the method of any of examples 21 though 31.

[0257] Example 34. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to perform the method of any of examples 21 through 32.

[0258] Example 41. A method comprising: obtaining, by processing circuitry, a brain signal representative of electrical activity of a brain of a patient; obtaining, by the processing circuitry, one or more values of a stimulation parameter that at least partially defines electrical stimulation deliverable to a portion of the brain of the patient; and outputting, for display by a user interface, a graph comprising a first trace of the brain signal for a period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

[0259] Example 42. The method of example 41, wherein the graph is a first graph and the period of time is a first period of time, and wherein the method further comprises: outputting, for display by the user interface, a second graph comprising a third trace of the brain signal for a second period of time and a fourth trace of the one or more values of the stimulation parameter for the second period of time, wherein the second period of time is greater than the first period of time, and wherein the second period of time comprises the first period of time.

[0260] Example 43. The method of any of examples 41 and 42, further comprising outputting, for display by the user interface, at least one of an upper threshold for the brain signal or a lower threshold for the brain signal on the graph.

[0261] Example 44. The method of any of examples 41 though 43, further comprising, outputting, for display by the user interface, at least one of a lower limit for the stimulation parameter or an upper limit for the stimulation parameter on the graph.

[0262] Example 45. The method of any of examples 41 though 44, further comprising controlling a medical device to limit the stimulation parameter between at least one of a lower limit of the stimulation parameter corresponding to an upper threshold of the brain signal or an upper limit of the stimulation parameter corresponding to a lower threshold of the brain signal.

[0263] Example 46. The method of any of examples 41 though 45, wherein the first trace of the brain signal for a period of time and the second trace of the one or more values of the stimulation parameter for the period of time comprise near real-time values for the brain signal and the stimulation parameter.

[0264] Example 47. The method of any of examples 41 though 46, wherein the brain signal comprises one or more local field potential signals.

[0265] Example 48. The method of any of examples 41 though 47, wherein an external programmer comprises the processing circuitry, the external programmer configured to control the medical device configured to be coupled to the one or more electrical leads.

[0266] Example 49. An external programmer configured to perform the method of any of examples 41 though 48.

[0267] Example 50. An external programmer comprising means for performing the method of any of examples 41 though 48.

[0268] Example 51. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to perform the method of any of examples 41 through 48.

[0269] Example 61. A method comprising: obtaining, by processing circuitry and from a first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time; obtaining, by the processing circuitry, stimulation parameter information comprising one or more values of a stimulation parameter that at least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and outputting, for display by a user interface, a graph comprising a first trace of the brain signal information for the period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

[0270] Example 62. The method of example 61, further comprising: obtaining one or more patient events corresponding to a respective user input received during the period of time; and outputting, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

[0271] Example 63. The method of any of examples 61 and 62, further comprising: obtaining one or more system identified events corresponding to respective automatically identified events during the period of time; and outputting, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

[0272] Example 64. The method of example 61, further comprising: obtaining one or more patient events corresponding to a respective user input received during the period of time; outputting, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph; obtaining one or more system identified events corresponding to respective automatically identified events during the period of time; and outputting, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

[0273] Example 65. The method of any of examples 61 though 63, further comprising: receiving user input selecting a marker presented on the graph; and responsive to receiving the user input, displaying a pop up graph of the brain signal information corresponding to a time associated with the marker, the pop up graph comprising a spectral graph of the brain signal information at the time associated with the marker.

[0274] Example 66. The method of any of examples 61 though 65, wherein: the brain signal information comprises electrical activity of a first hemisphere of the brain and a second hemisphere of the brain over the period of time, the stimulation parameter information comprises one or more values of a first stimulation parameter that at least partially defines electrical stimulation delivered to the first hemisphere of the brain and one or more values of a second stimulation parameter that at least partially defines electrical stimulation delivered to the second hemisphere of the brain during the period of time; and the graph is a first graph comprising the first trace of the brain signal information comprising electrical activity of the first hemisphere for the period of time and the second trace of the one or more values of the first stimulation parameter for the period of time, and wherein the method further comprises: outputting, for display by the user interface, a second graph on a same screen as the first graph, wherein the second graph comprises a third trace of the brain signal information comprising electrical activity of the second hemisphere for the period of time and a fourth trace of the one or more values of the second stimulation parameter for the period of time.

[0275] Example 67. The method of any of examples 61 and 66, wherein the graph comprises: at least one of an upper threshold or a lower threshold displayed with the first trace of the brain signal information; and at least one of a lower limit or an upper limit displayed with the second trace of the one or more values of the stimulation parameter.

[0276] Example 68. The method of any of examples 61 though 67, wherein the brain signal comprises one or more local field potential signals.

[0277] Example 69. The method of any of examples 61 though 68, wherein an external programmer comprises the processing circuitry, the external programmer configured to control the medical device configured to be coupled to the one or more electrical leads.

[0278] Example 70. An external programmer comprising: a first memory; and processing circuitry configured to: obtain, from the first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time; obtain stimulation parameter information comprising one or more values of a stimulation parameter that at least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and output, for display by a user interface, a graph comprising a first trace of the brain signal information for the period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

[0279] Example 71. The external programmer of example 70, wherein the processing circuitry is further configured to:

obtain one or more patient events corresponding to a respective user input received during the period of time; and output, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

[0280] Example 72. The external programmer of any of examples 70 and 71, wherein the processing circuitry is further configured to: obtain one or more system identified events corresponding to respective automatically identified events during the period of time; and output, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

[0281] Example 73. The external programmer of any of examples 70 though 72, wherein the processing circuitry is further configured to: obtain one or more patient events corresponding to a respective user input received during the period of time; output, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph; obtain one or more system identified events corresponding to respective automatically identified events during the period of time; and output, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

[0282] Example 74. The external programmer of any of examples 70 though 73, wherein the processing circuitry is further configured to: receive user input selecting a marker presented on the graph; and responsive to receiving the user input, control a display to display a pop up graph of the brain signal information corresponding to a time associated with the marker, the pop up graph comprising a spectral graph of the brain signal information at the time associated with the marker.

[0283] Example 75. The external programmer of any of examples 70 though 74, wherein: the brain signal information comprises electrical activity of a first hemisphere of the brain and a second hemisphere of the brain over the period of time, the stimulation parameter information comprises one or more values of a first stimulation parameter that at least partially defines electrical stimulation delivered to the first hemisphere of the brain and one or more values of a second stimulation parameter that at least partially defines electrical stimulation delivered to the second hemisphere of the brain during the period of time; and the graph is a first graph comprising the first trace of the brain signal information comprising electrical activity of the first hemisphere for the period of time and the second trace of the one or more values of the first stimulation parameter for the period of time, and wherein the processing circuitry is further configured to: output, for display by the user interface, a second graph on a same screen as the first graph, wherein the second graph comprises a third trace of the brain signal information comprising electrical activity of the second hemisphere for the period of time and a fourth trace of the one or more values of the second stimulation parameter for the period of time.

[0284] Example 76. The external programmer of any of examples 70 through and 75, wherein the graph comprises: at least one of an upper threshold or a lower threshold displayed with the first trace of the brain signal information; and at least one of a lower limit or an upper limit displayed with the second trace of the one or more values of the stimulation parameter.

[0285] Example 77. The external programmer of any of examples 70 though 76, wherein the brain signal comprises one or more local field potential signals.

[0286] Example 78. The external programmer of any of examples 70 though 77, wherein the external programmer is configured to control a medical device configured to be coupled to the one or more electrical leads.

[0287] Example 79. An external programmer comprising means for performing the method of any of examples 61 though 69.

[0288] Example 80. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to obtain, from a first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time; obtain stimulation parameter information comprising one or more values of a stimulation parameter that at least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and output, for display by a user interface, a graph comprising a first trace of the brain signal information for the period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

[0289] Example 81. A method comprising: obtaining, by processing circuitry, brain signal information representative of electrical activity of a brain of a patient over a period of time; determining, by the processing circuitry, a first amount of time an amplitude of the brain signal information was greater than an upper threshold during the period of time; determining, by the processing circuitry, a second amount of time the amplitude of the brain signal information was less than a lower threshold during the period of time; determining, by the processing circuitry, a third amount of time the amplitude of the brain signal information was between the upper threshold and the lower threshold during the period of time; and outputting, for display via a user interface, a representation of the first amount of time, the second amount of time, and the third amount of time.

[0290] Example 82. The method of example 81, wherein the amplitude of the brain signal information above the upper threshold indicates ineffective electrical stimulation for treating a symptom of the patient.

[0291] Example 83. The method of any of examples 81 and 82, wherein the amplitude of the brain signal information below the lower threshold indicates a side effect caused by the electrical stimulation delivered to the patient.

[0292] Example 84. The method of any of examples 81 though 83, wherein the representation comprises a table having respective entries for each of the first amount of time, the second amount of time, and the third amount of time.

[0293] Example 85. The method of any of examples 81 though 84, wherein the representation comprises a graph illustrating each of the first amount of time, the second amount of time, and the third amount of time.

[0294] Example 86. The method of any of examples 81 though 85, further comprising outputting, as part of the representation, at least one of an average amplitude of stimulation, an amount of time stimulation was turned off due to adaptive stimulation being delivered to the patient, or an amount of time adaptive stimulation was delivered to the patient during the period of time.

[0295] Example 87. The method of any of examples 81 though 86, wherein the brain signal information comprises one or more local field potential signals.

[0296] Example 88. The method of any of examples 81 though 87, wherein an external programmer comprises the processing circuitry, the external programmer configured to control the medical device configured to be coupled to the one or more electrical leads.

[0297] Example 89. An external programmer configured to perform the method of any of examples 81 though 88.

[0298] Example 90. An external programmer comprising means for performing the method of any of examples 81 though 88.

[0299] Example 91. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to perform the method of any of examples 81 through 88.

[0300] Example 101. A method comprising: receiving, by processing circuitry, an indication of an event at a time; responsive to receiving the indication of the event, storing spectral information for a brain signal recorded at the time; and outputting, for display by a user interface, a graph indicating the spectral information for the brain signal recorded at the time.

[0301] Example 102. The method of example 101, wherein the indication is a first indication, the event is a first event, the brain signal is a first brain signal, and the time is a first time, and wherein the method further comprises: receiving, by processing circuitry, a second indication of a second event at a second time; responsive to receiving the second indication of the second event, storing spectral information for a second brain signal recorded at the second time; and outputting, for display by a user interface, the graph indicating the spectral information for the first brain signal recorded at the first time and spectral information for the second brain signal recorded at the second time.

[0302] Example 103. The method of any of examples 101 and 102, wherein receiving the indication of the event comprises receiving, via a user interface, user input indicating the event.

[0303] Example 104. The method of any of examples 101 though 103, further comprising: responsive to receiving the indication of the event, recording the brain signal; and subsequent to recording the brain signal, generating the spectral information for the brain signal.

[0304] Example 105. The method of any of examples 101 though 104, wherein storing the spectral information for the brain signal recorded at the time comprises selecting the brain signal from a rolling buffer comprising brain signals sensed over a period comprising the time.

[0305] Example 106. The method of any of examples 101 though 105, wherein receiving the indication of the event comprises automatically identifying, by the processing circuitry, the event from at least one of brain signal information or an electrical stimulation status.

[0306] Example 107. The method of any of examples 101 though 106, wherein the event comprises at least one of a patient fall, a medication time, a patient symptom, or a stimulation delivery event.

[0307] Example 108. The method of any of examples 101 though 107, wherein the brain signal recorded at the time is a one brain signal of a plurality of brain signals recorded at respective times, and wherein the method further comprises: receiving user input selecting at least the one brain signal from the plurality of brain signals; and outputting, for display via the user interface, the spectral information for the at least one brain signal selected according to the user input.

[0308] Example 109. The method of any of examples 101 though 108, wherein the graph displays the spectral information as a magnitude of the brain signal vs. frequency of the brain signal.

[0309] Example 110. The method of any of examples 101 though 109, wherein the brain signal comprises one or more local field potential signals.

[0310] Example 111. The method of any of examples 101 though 110, wherein an external programmer comprises the processing circuitry, the external programmer configured to control the medical device configured to be coupled to the one or more electrical leads.

[0311] Example 112. An external programmer configured to perform the method of any of examples 101 through 111.

[0312] Example 113. An external programmer comprising means for performing the method of any of examples 101 through 111.

[0313] Example 114. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to perform the method of any of examples 101 through 111.

[0314] Example 115. A system comprising an implantable deep brain stimulation device and the external programmer of any of examples 10, 11, 32, 33, 49, 50, 69, 70, 89, 90, 112, and 113.

[0315] The techniques described in this disclosure may be implemented, at least in part, in hardware, software, firmware or any combination thereof. For example, various aspects of the described techniques may be implemented within one or more processors, such as fixed function processing circuitry and/or programmable processing circuitry, including one or more microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components. The term "processor" or "processing circuitry" may generally refer to any of the foregoing logic circuitry, alone or in combination with other logic circuitry, or any other equivalent circuitry. A control unit comprising hardware may also perform one or more of the techniques of this disclosure.

[0316] Such hardware, software, and firmware may be implemented within the same device or within separate devices to support the various operations and functions described in this disclosure. In addition, any of the described units, modules or components may be implemented together or separately as discrete but interoperable logic devices. Depiction of different features as modules or units is intended to highlight different functional aspects and does not necessarily imply that such modules or units must be realized by separate hardware or software components. Rather, functionality associated with one or more modules

or units may be performed by separate hardware or software components, or integrated within common or separate hardware or software components.

[0317] The techniques described in this disclosure may also be embodied or encoded in a computer-readable medium, such as a computer-readable storage medium, containing instructions. Instructions embedded or encoded in a computer-readable storage medium may cause a programmable processor, or other processor, to perform the method, e.g., when the instructions are executed. Computer readable storage media may include random access memory (RAM), read only memory (ROM), programmable read only memory (PROM), erasable programmable read only memory (EPROM), electronically erasable programmable read only memory (EEPROM), flash memory, a hard disk, a CD-ROM, a floppy disk, a cassette, magnetic media, optical media, or other computer readable media.

[0318] Various examples have been described. These and other examples are within the scope of the following claims.

What is claimed is:

1. A method comprising:

obtaining, by processing circuitry and from a first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time;

obtaining, by the processing circuitry, stimulation parameter information comprising one or more values of a stimulation parameter that at least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and

outputting, for display by a user interface, a graph comprising a first trace of the brain signal information for the period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

2. The method of claim **1**, further comprising:

obtaining one or more patient events corresponding to a respective user input received during the period of time; and

outputting, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

3. The method of claim **1**, further comprising:

obtaining one or more system identified events corresponding to respective automatically identified events during the period of time; and

outputting, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

4. The method of claim **1**, further comprising:

obtaining one or more patient events corresponding to a respective user input received during the period of time;

outputting, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph;

obtaining one or more system identified events corresponding to respective automatically identified events during the period of time; and

outputting, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

5. The method of claim **1**, further comprising:

receiving user input selecting a marker presented on the graph; and

responsive to receiving the user input, displaying a pop up graph of the brain signal information corresponding to a time associated with the marker, the pop up graph comprising a spectral graph of the brain signal information at the time associated with the marker.

6. The method of claim **1**, wherein:

the brain signal information comprises electrical activity of a first hemisphere of the brain and a second hemisphere of the brain over the period of time,

the stimulation parameter information comprises one or more values of a first stimulation parameter that at least partially defines electrical stimulation delivered to the first hemisphere of the brain and one or more values of a second stimulation parameter that at least partially defines electrical stimulation delivered to the second hemisphere of the brain during the period of time; and

the graph is a first graph comprising the first trace of the brain signal information comprising electrical activity of the first hemisphere for the period of time and the second trace of the one or more values of the first stimulation parameter for the period of time, and wherein the method further comprises:

outputting, for display by the user interface, a second graph on a same screen as the first graph, wherein the second graph comprises a third trace of the brain signal information comprising electrical activity of the second hemisphere for the period of time and a fourth trace of the one or more values of the second stimulation parameter for the period of time.

7. The method of claim **1**, wherein the graph comprises:

at least one of an upper threshold or a lower threshold displayed with the first trace of the brain signal information; and

at least one of a lower limit or an upper limit displayed with the second trace of the one or more values of the stimulation parameter.

8. The method of claim **1**, wherein the brain signal comprises one or more local field potential signals.

9. The method of claim **1**, wherein an external programmer comprises the processing circuitry, the external programmer configured to control the medical device configured to be coupled to the one or more electrical leads.

10. An external programmer comprising:

a first memory; and

processing circuitry configured to:

obtain, from the first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time;

obtain stimulation parameter information comprising one or more values of a stimulation parameter that at

least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and

output, for display by a user interface, a graph comprising a first trace of the brain signal information for the period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

11. The external programmer of claim **10**, wherein the processing circuitry is further configured to:

obtain one or more patient events corresponding to a respective user input received during the period of time; and

output, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

12. The external programmer of claim **10**, wherein the processing circuitry is further configured to:

obtain one or more system identified events corresponding to respective automatically identified events during the period of time; and

output, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

13. The external programmer of claim **10**, wherein the processing circuitry is further configured to:

obtain one or more patient events corresponding to a respective user input received during the period of time;

output, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph;

obtain one or more system identified events corresponding to respective automatically identified events during the period of time; and

output, for display by the user interface, one or more respective second markers representing the one or more patient events on the graph, wherein the one or more respective second markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

14. The external programmer of claim **10**, wherein the processing circuitry is further configured to:

receive user input selecting a marker presented on the graph; and

responsive to receiving the user input, control a display to display a pop up graph of the brain signal information corresponding to a time associated with the marker, the pop up graph comprising a spectral graph of the brain signal information at the time associated with the marker.

15. The external programmer of claim **10**, wherein:

the brain signal information comprises electrical activity of a first hemisphere of the brain and a second hemisphere of the brain over the period of time,

the stimulation parameter information comprises one or more values of a first stimulation parameter that at least partially defines electrical stimulation delivered to the first hemisphere of the brain and one or more values of a second stimulation parameter that at least partially defines electrical stimulation delivered to the second hemisphere of the brain during the period of time; and

the graph is a first graph comprising the first trace of the brain signal information comprising electrical activity of the first hemisphere for the period of time and the second trace of the one or more values of the first stimulation parameter for the period of time, and wherein the processing circuitry is further configured to:

output, for display by the user interface, a second graph on a same screen as the first graph, wherein the second graph comprises a third trace of the brain signal information comprising electrical activity of the second hemisphere for the period of time and a fourth trace of the one or more values of the second stimulation parameter for the period of time.

16. The external programmer of claim **10**, wherein the graph comprises:

at least one of an upper threshold or a lower threshold displayed with the first trace of the brain signal information; and

at least one of a lower limit or an upper limit displayed with the second trace of the one or more values of the stimulation parameter.

17. The external programmer of claim **10**, wherein the brain signal comprises one or more local field potential signals.

18. The external programmer of claim **10**, wherein the external programmer is configured to control a medical device configured to be coupled to the one or more electrical leads.

19. A non-transitory computer-readable medium comprising instructions that, when executed, control processing circuitry to:

obtain, from a first memory, brain signal information representative of electrical activity of a brain of a patient over a period of time;

obtain stimulation parameter information comprising one or more values of a stimulation parameter that at least partially defines electrical stimulation delivered to a portion of the brain of the patient during the period of time; and

output, for display by a user interface, a graph comprising a first trace of the brain signal information for the period of time and a second trace of the one or more values of the stimulation parameter for the period of time.

20. The non-transitory computer-readable medium of claim **19**, further comprising instructions that cause the processing circuitry to:

obtain one or more patient events corresponding to a respective user input received during the period of time; and

output, for display by the user interface, one or more respective first markers representing the one or more patient events on the graph, wherein the one or more respective first markers are located at a corresponding time at which the respective user input was received along a time axis of the graph.

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