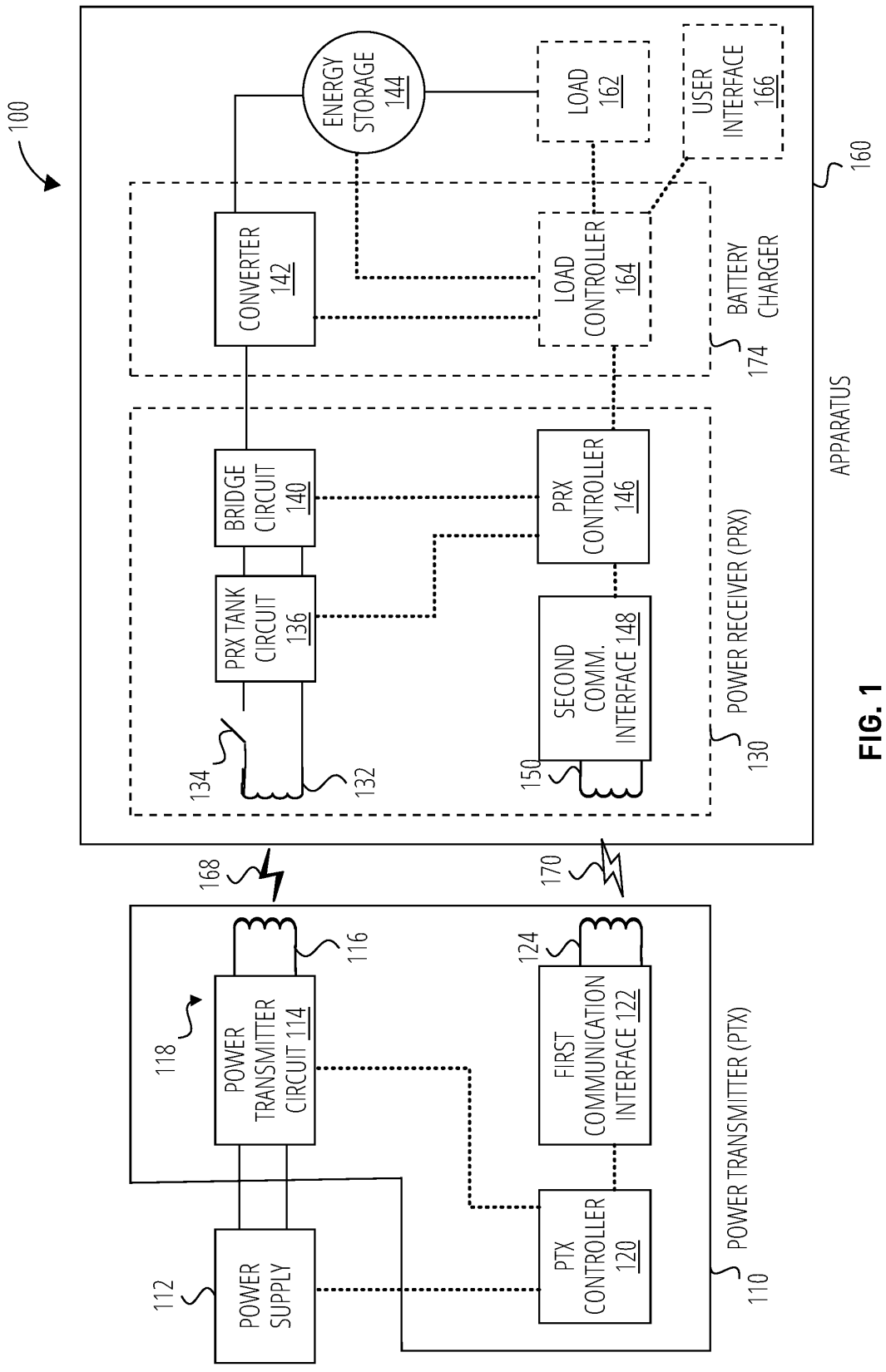
100
ENERGY STORAGE 144
LOAD 162
USER INTERFACE 166
160
CONVERTER 142
LOAD CONTROLLER 164
BATTERY CHARGER 174
APPARATUS
BRIDGE CIRCUIT 140
PRX CONTROLLER 146
PRX TANK CIRCUIT 136
SECOND COMM. INTERFACE 148
POWER RECEIVER (PRX) 130
134
132
150
168
170
116
124
118
POWER TRANSMITTER CIRCUIT 114
FIRST COMMUNICATION INTERFACE 122
112
POWER SUPPLY
PTX CONTROLLER 120
POWER TRANSMITTER (PTX) 110

FIG. 1

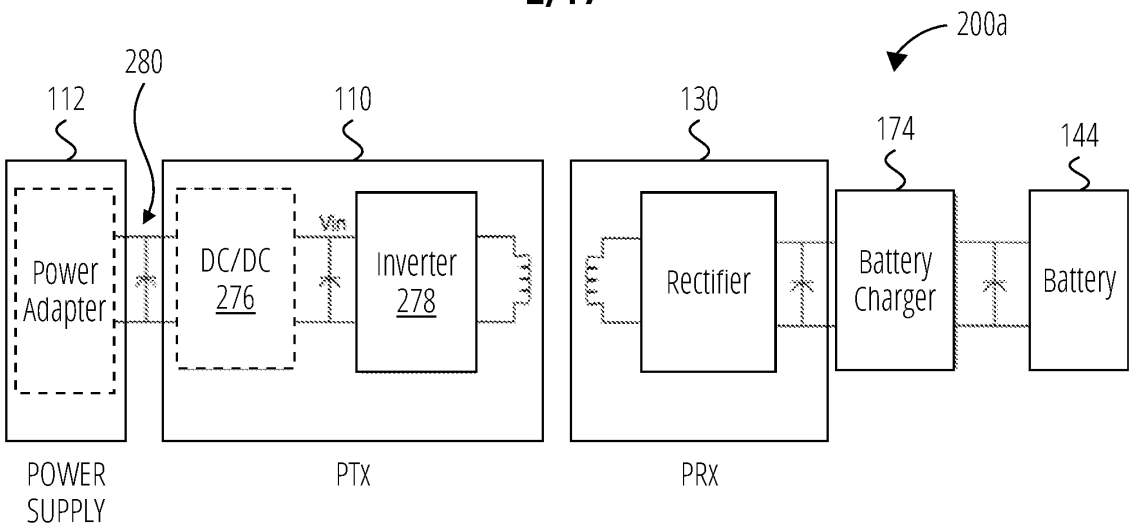


FIG. 2A

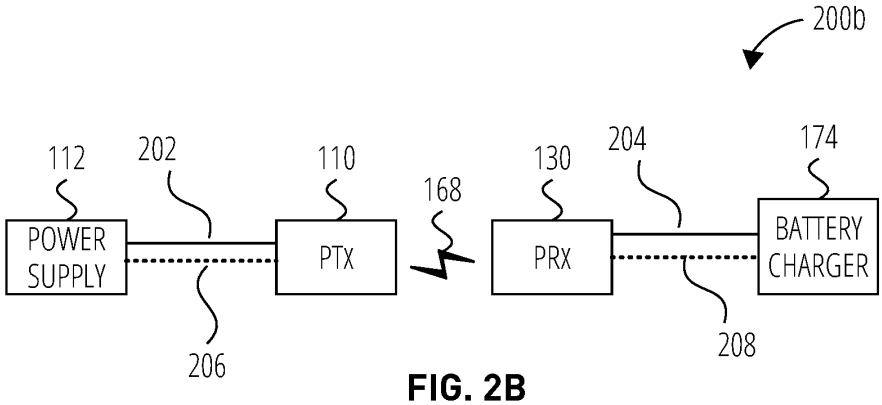


FIG. 2B

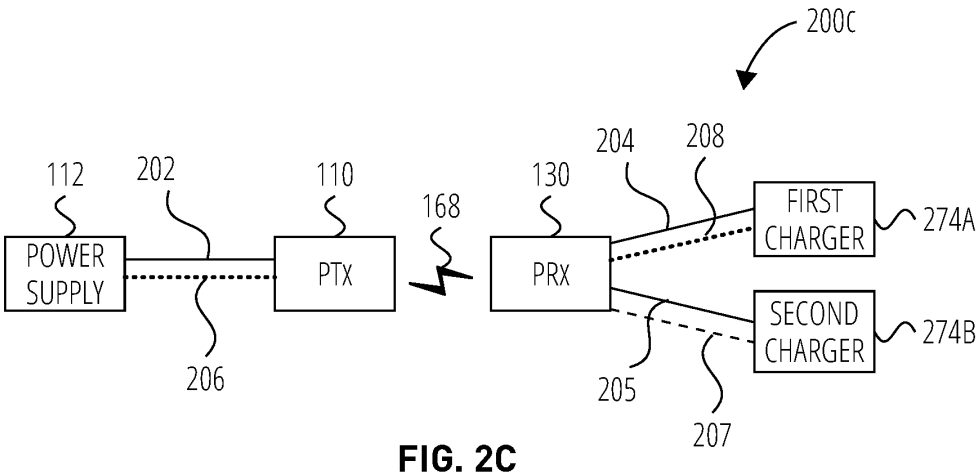


FIG. 2C

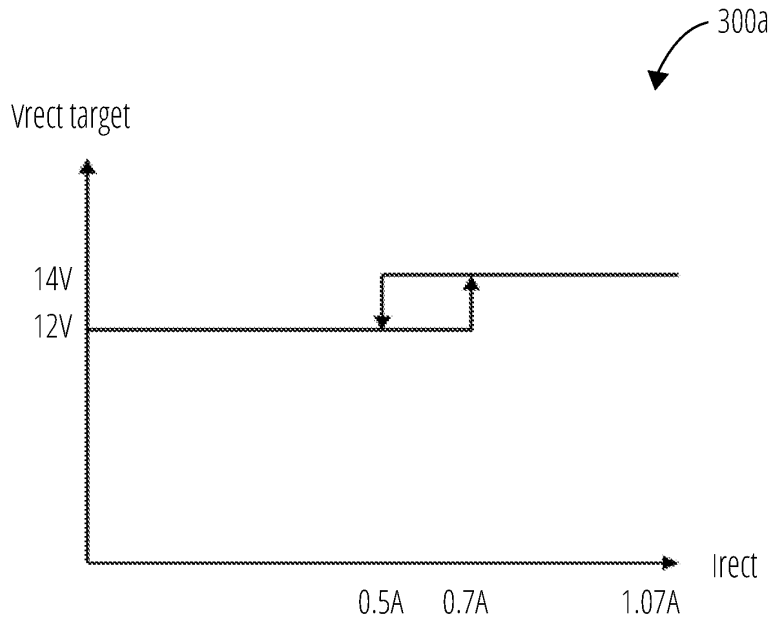
300a
Vrect target
14V
12V
Irect
0.5A
0.7A
1.07A

FIG. 3A

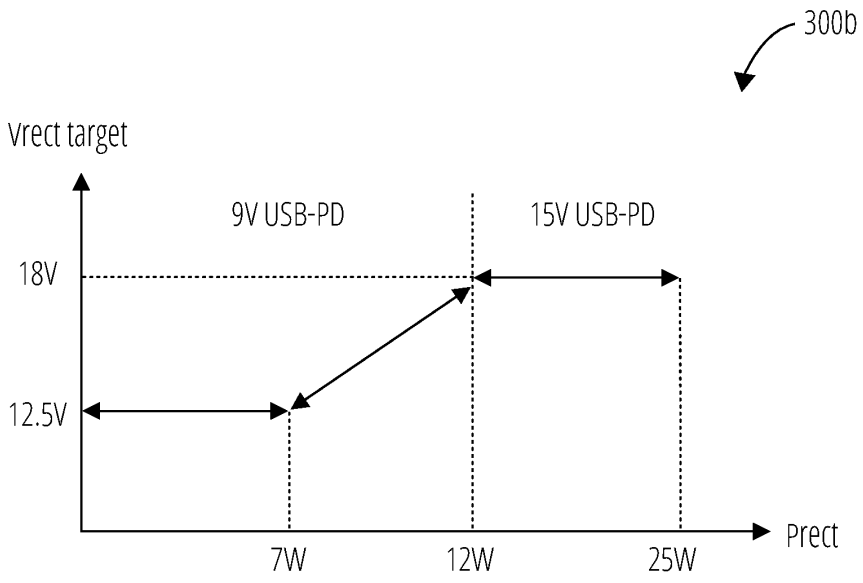
300b
Vrect target
9V USB-PD
15V USB-PD
18V
12.5V
Prect
7W
12W
25W

FIG. 3B

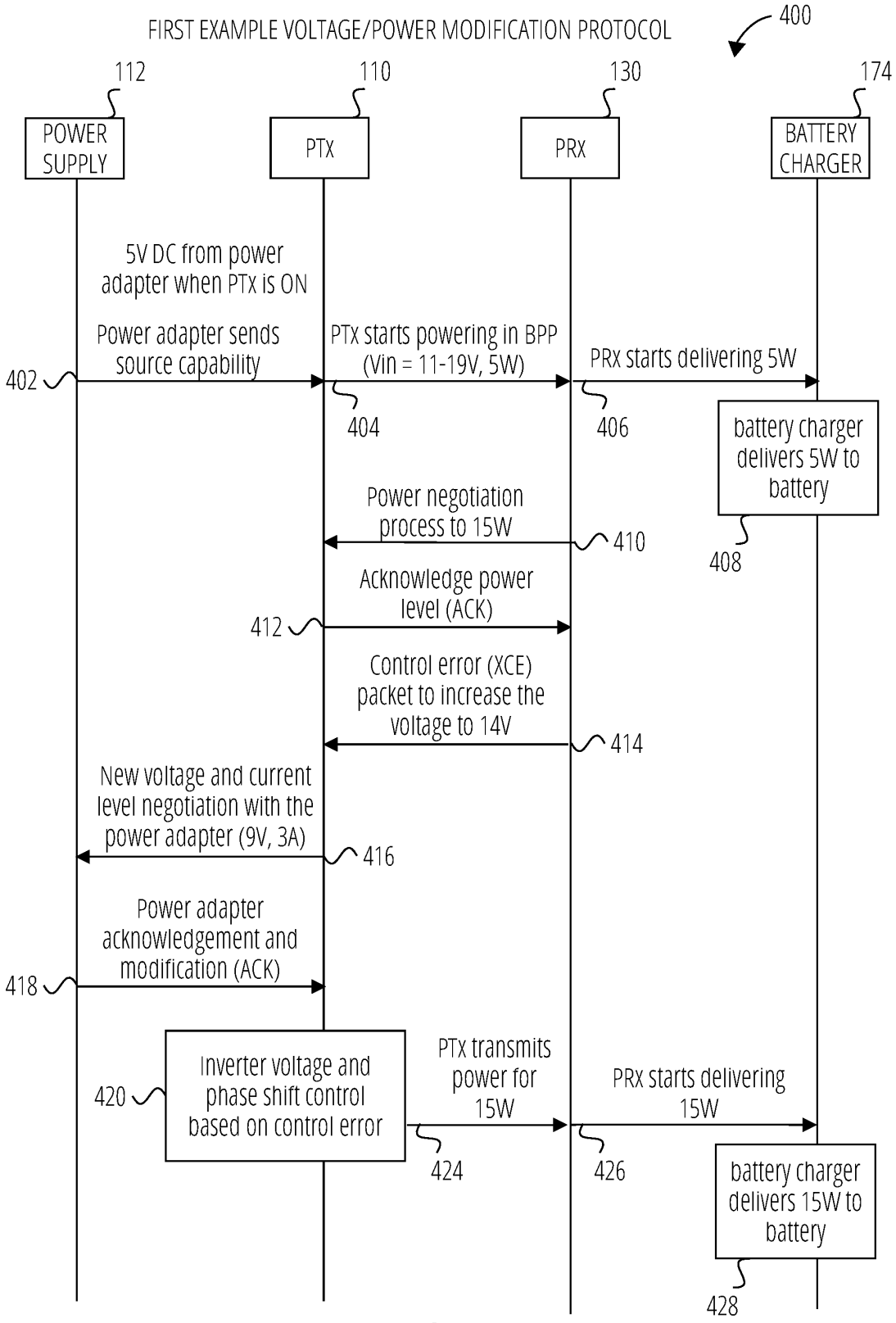
FIRST EXAMPLE VOLTAGE/POWER MODIFICATION PROTOCOL
400
112
110
130
174
POWER SUPPLY
PTx
PRx
BATTERY CHARGER
5V DC from power adapter when PTx is ON
Power adapter sends source capability
402
PTx starts powering in BPP (Vin = 11-19V, 5W)
404
PRx starts delivering 5W
406
battery charger delivers 5W to battery
408
Power negotiation process to 15W
410
Acknowledge power level (ACK)
412
Control error (XCE) packet to increase the voltage to 14V
414
New voltage and current level negotiation with the power adapter (9V, 3A)
416
Power adapter acknowledgement and modification (ACK)
418
Inverter voltage and phase shift control based on control error
420
PTx transmits power for 15W
424
PRx starts delivering 15W
426
battery charger delivers 15W to battery
428

FIG. 4

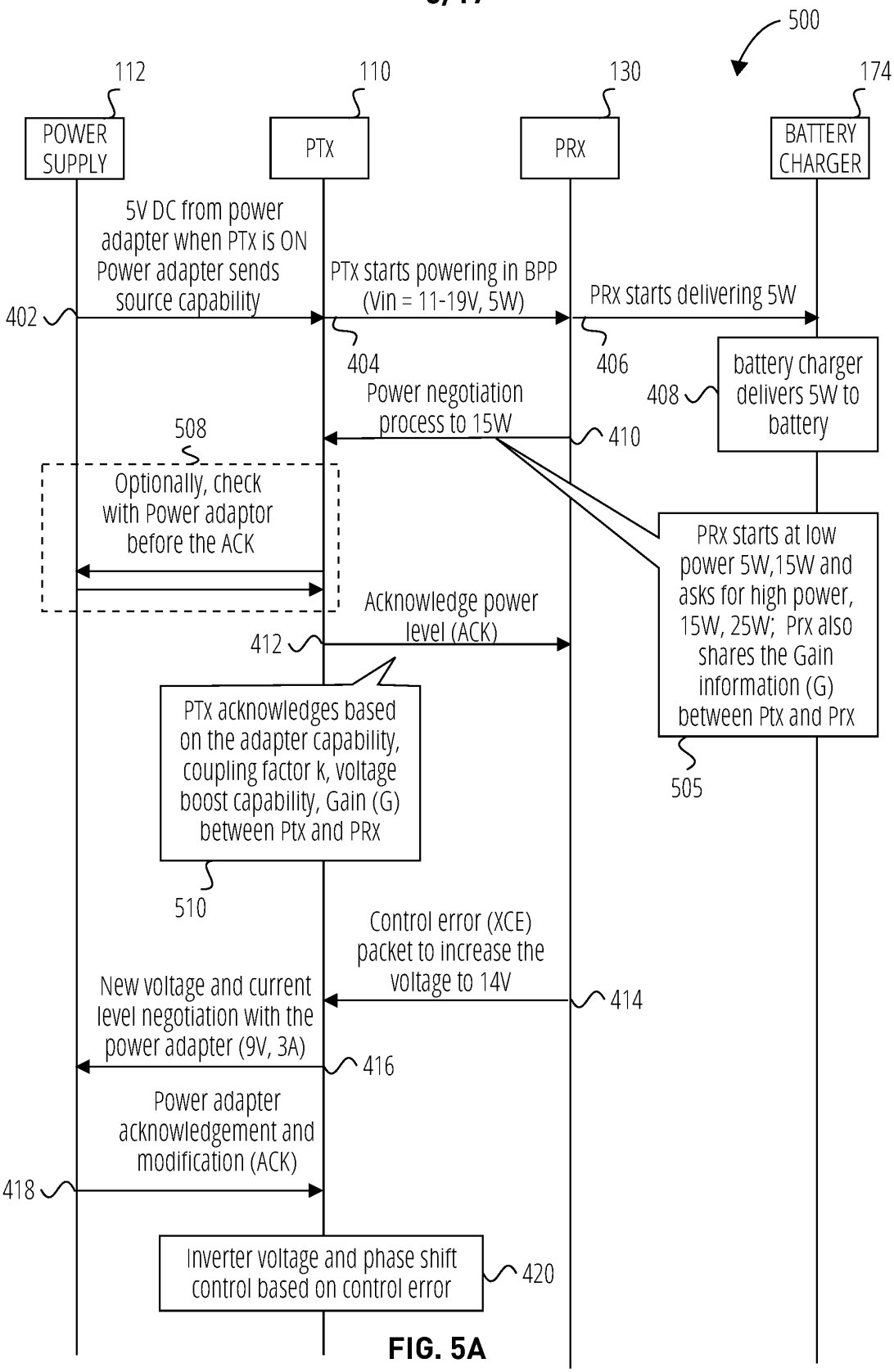
500
112
110
130
174
POWER SUPPLY
PTx
PRx
BATTERY CHARGER
5V DC from power adapter when PTx is ON Power adapter sends source capability
402
PTx starts powering in BPP (Vin = 11-19V, 5W)
404
PRx starts delivering 5W
406
battery charger delivers 5W to battery
408
Power negotiation process to 15W
410
508
Optionally, check with Power adaptor before the ACK
PRx starts at low power 5W,15W and asks for high power, 15W, 25W; Prx also shares the Gain information (G) between Ptx and Prx
505
Acknowledge power level (ACK)
412
PTx acknowledges based on the adapter capability, coupling factor k, voltage boost capability, Gain (G) between Ptx and PRx
510
Control error (XCE) packet to increase the voltage to 14V
414
New voltage and current level negotiation with the power adapter (9V, 3A)
416
Power adapter acknowledgement and modification (ACK)
418
Inverter voltage and phase shift control based on control error
420

FIG. 5A

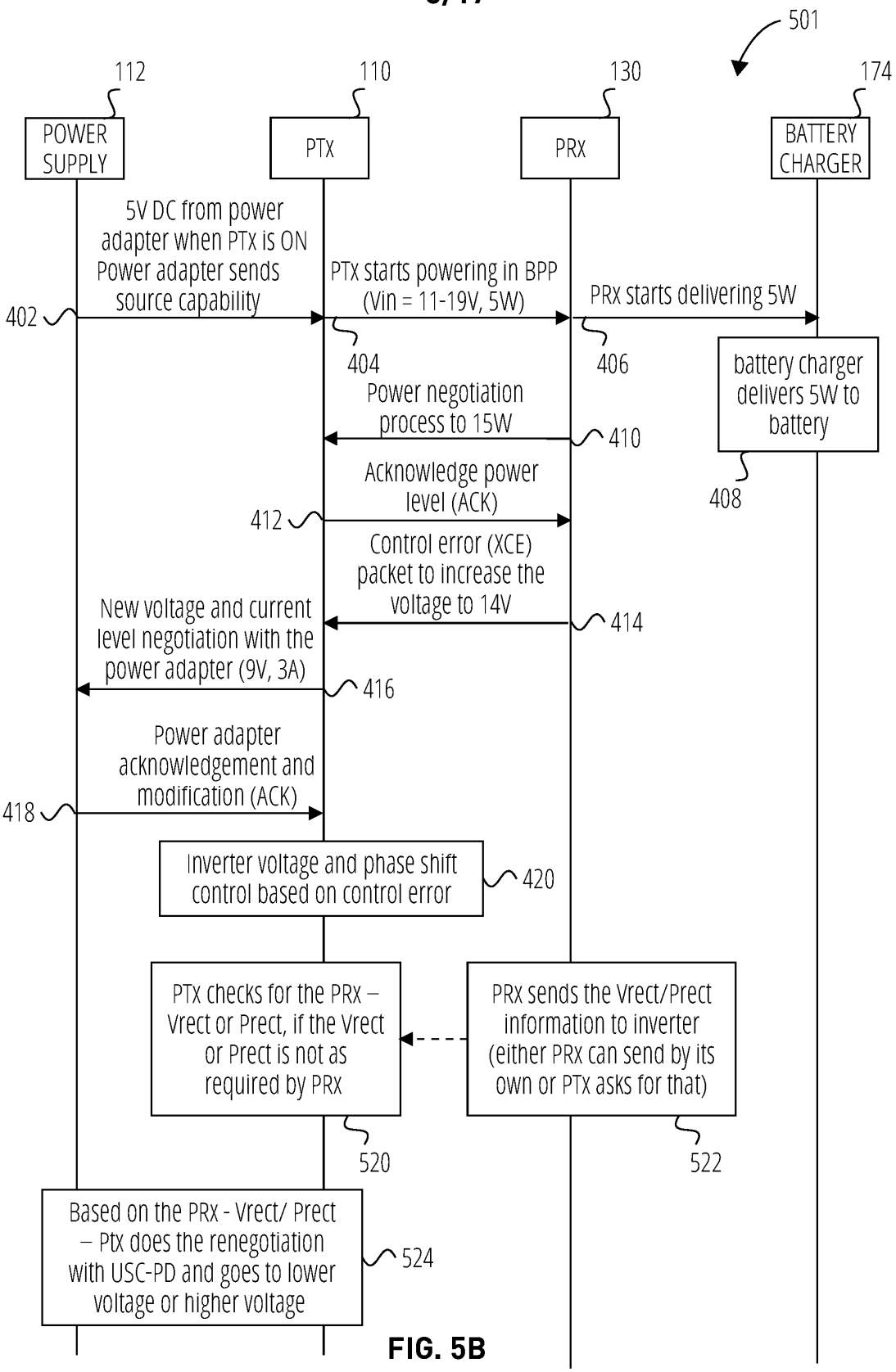
501
112
110
130
174
POWER SUPPLY
PTx
PRx
BATTERY CHARGER
5V DC from power adapter when PTx is ON Power adapter sends source capability
402
PTx starts powering in BPP (Vin = 11-19V, 5W)
404
PRx starts delivering 5W
406
battery charger delivers 5W to battery
408
Power negotiation process to 15W
410
Acknowledge power level (ACK)
412
Control error (XCE) packet to increase the voltage to 14V
414
New voltage and current level negotiation with the power adapter (9V, 3A)
416
Power adapter acknowledgement and modification (ACK)
418
Inverter voltage and phase shift control based on control error
420
PTx checks for the PRx – Vrect or Prect, if the Vrect or Prect is not as required by PRx
520
PRx sends the Vrect/Prect information to inverter (either PRx can send by its own or PTx asks for that)
522
Based on the PRx - Vrect/ Prect – Ptx does the renegotiation with USC-PD and goes to lower voltage or higher voltage
524

FIG. 5B

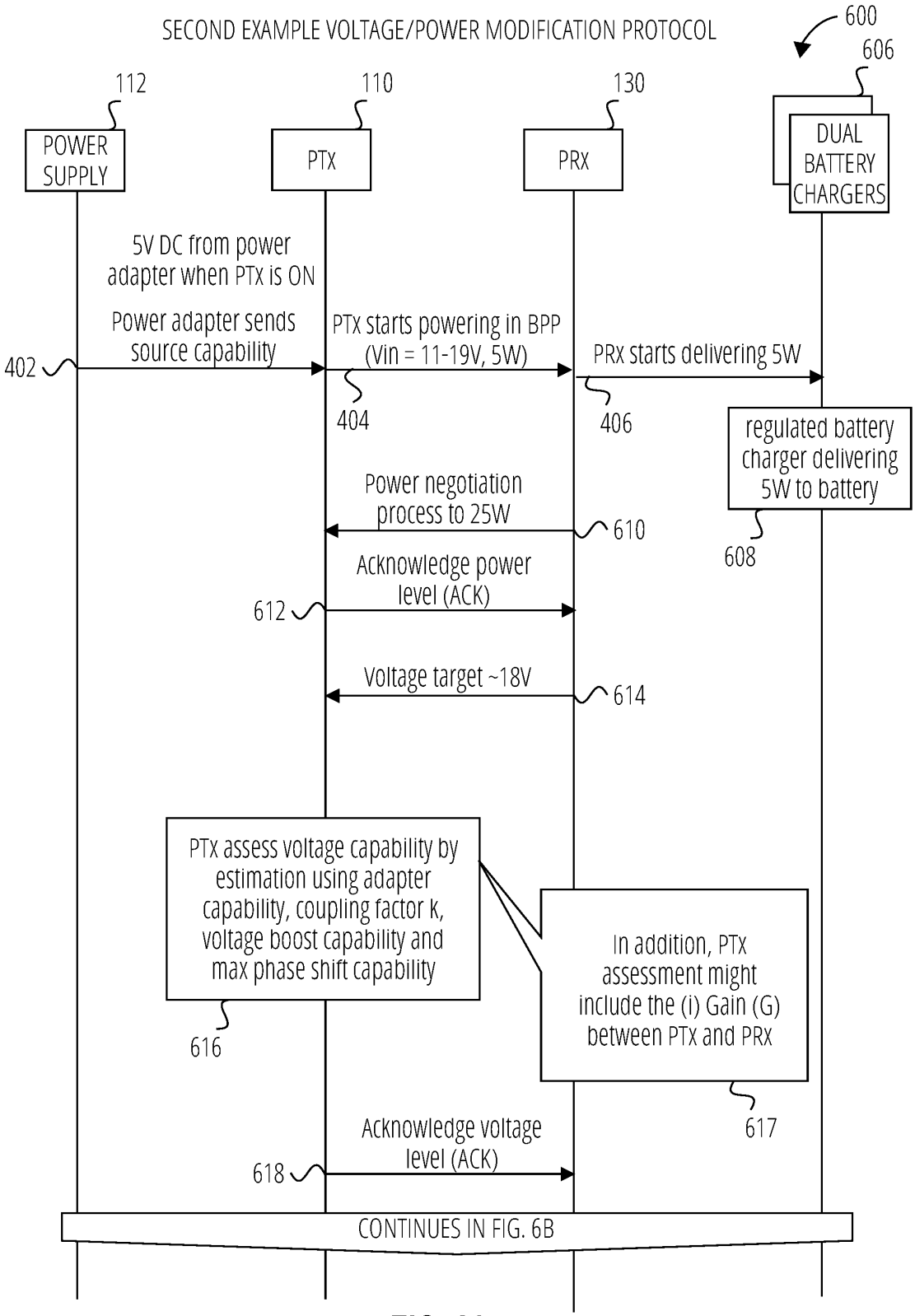
SECOND EXAMPLE VOLTAGE/POWER MODIFICATION PROTOCOL
600
606
112
110
130
POWER SUPPLY
PTx
PRx
DUAL BATTERY CHARGERS
5V DC from power adapter when PTx is ON
Power adapter sends source capability
402
PTx starts powering in BPP (Vin = 11-19V, 5W)
404
PRx starts delivering 5W
406
regulated battery charger delivering 5W to battery
608
Power negotiation process to 25W
610
Acknowledge power level (ACK)
612
Voltage target ~18V
614
PTx assess voltage capability by estimation using adapter capability, coupling factor k, voltage boost capability and max phase shift capability
616
In addition, PTx assessment might include the (i) Gain (G) between PTx and PRx
617
Acknowledge voltage level (ACK)
618
CONTINUES IN FIG. 6B

FIG. 6A

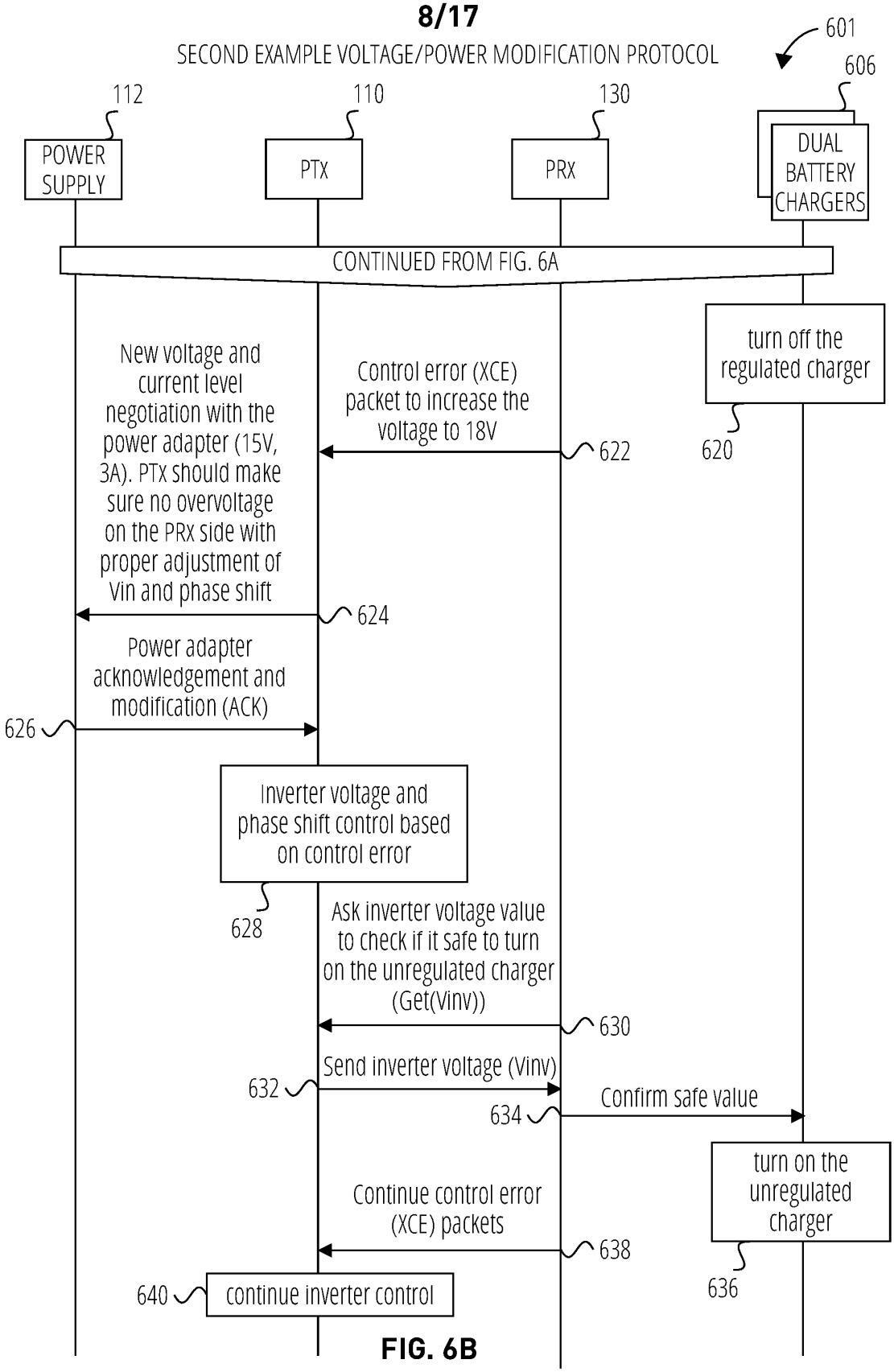
SECOND EXAMPLE VOLTAGE/POWER MODIFICATION PROTOCOL
601
606
112
110
130
POWER SUPPLY
PTx
PRx
DUAL BATTERY CHARGERS
CONTINUED FROM FIG. 6A
turn off the regulated charger
620
New voltage and current level negotiation with the power adapter (15V, 3A). PTx should make sure no overvoltage on the PRx side with proper adjustment of Vin and phase shift
Control error (XCE) packet to increase the voltage to 18V
622
624
Power adapter acknowledgement and modification (ACK)
626
Inverter voltage and phase shift control based on control error
628
Ask inverter voltage value to check if it safe to turn on the unregulated charger (Get(Vinv))
630
Send inverter voltage (Vinv)
632
Confirm safe value
634
turn on the unregulated charger
636
Continue control error (XCE) packets
638
640
continue inverter control

FIG. 6B

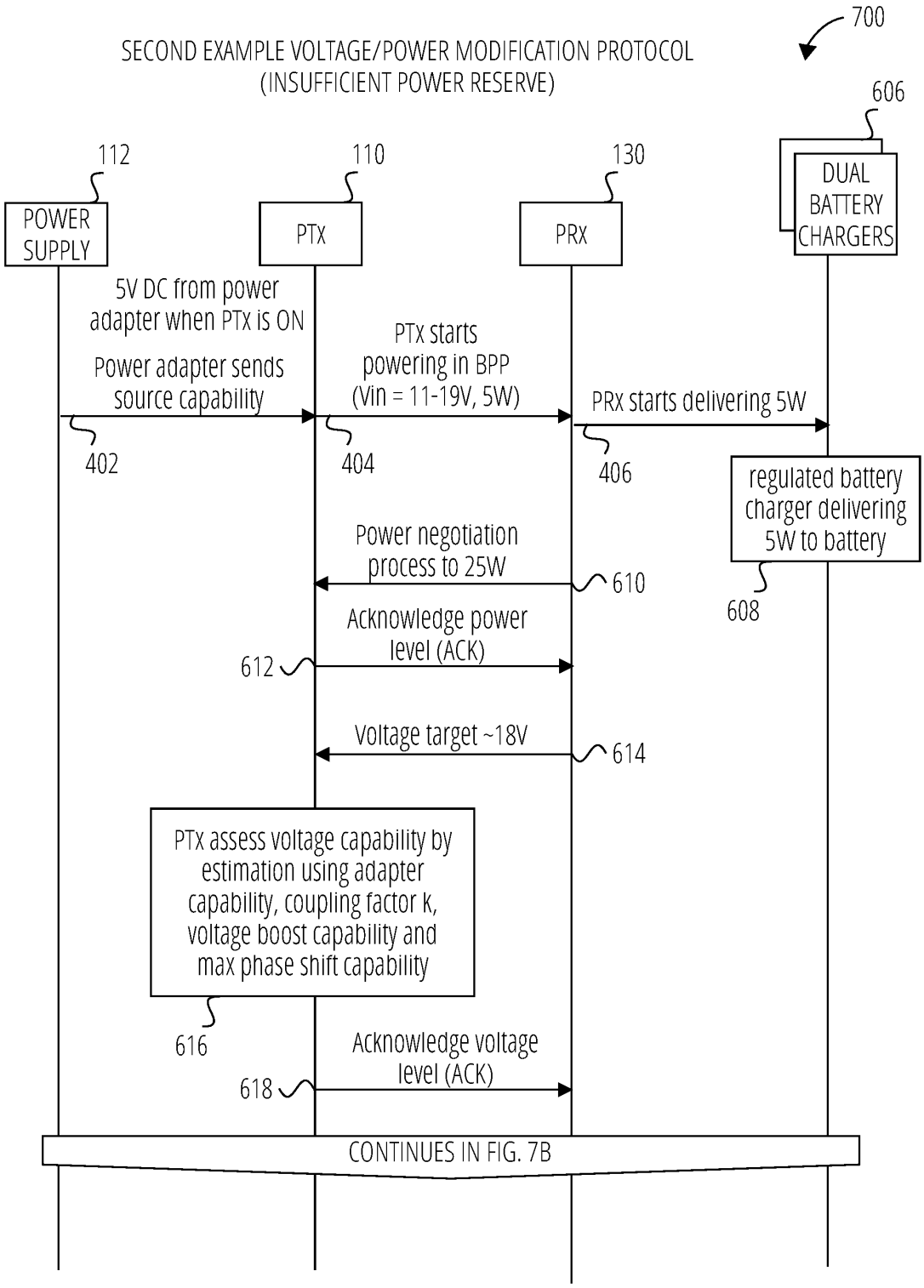
700
SECOND EXAMPLE VOLTAGE/POWER MODIFICATION PROTOCOL
(INSUFFICIENT POWER RESERVE)
606
112
110
130
POWER SUPPLY
PTx
PRx
DUAL BATTERY CHARGERS
5V DC from power adapter when PTx is ON
Power adapter sends source capability
PTx starts powering in BPP (Vin = 11-19V, 5W)
PRx starts delivering 5W
402
404
406
regulated battery charger delivering 5W to battery
608
Power negotiation process to 25W
610
Acknowledge power level (ACK)
612
Voltage target ~18V
614
PTx assess voltage capability by estimation using adapter capability, coupling factor k, voltage boost capability and max phase shift capability
616
Acknowledge voltage level (ACK)
618
CONTINUES IN FIG. 7B

FIG. 7A

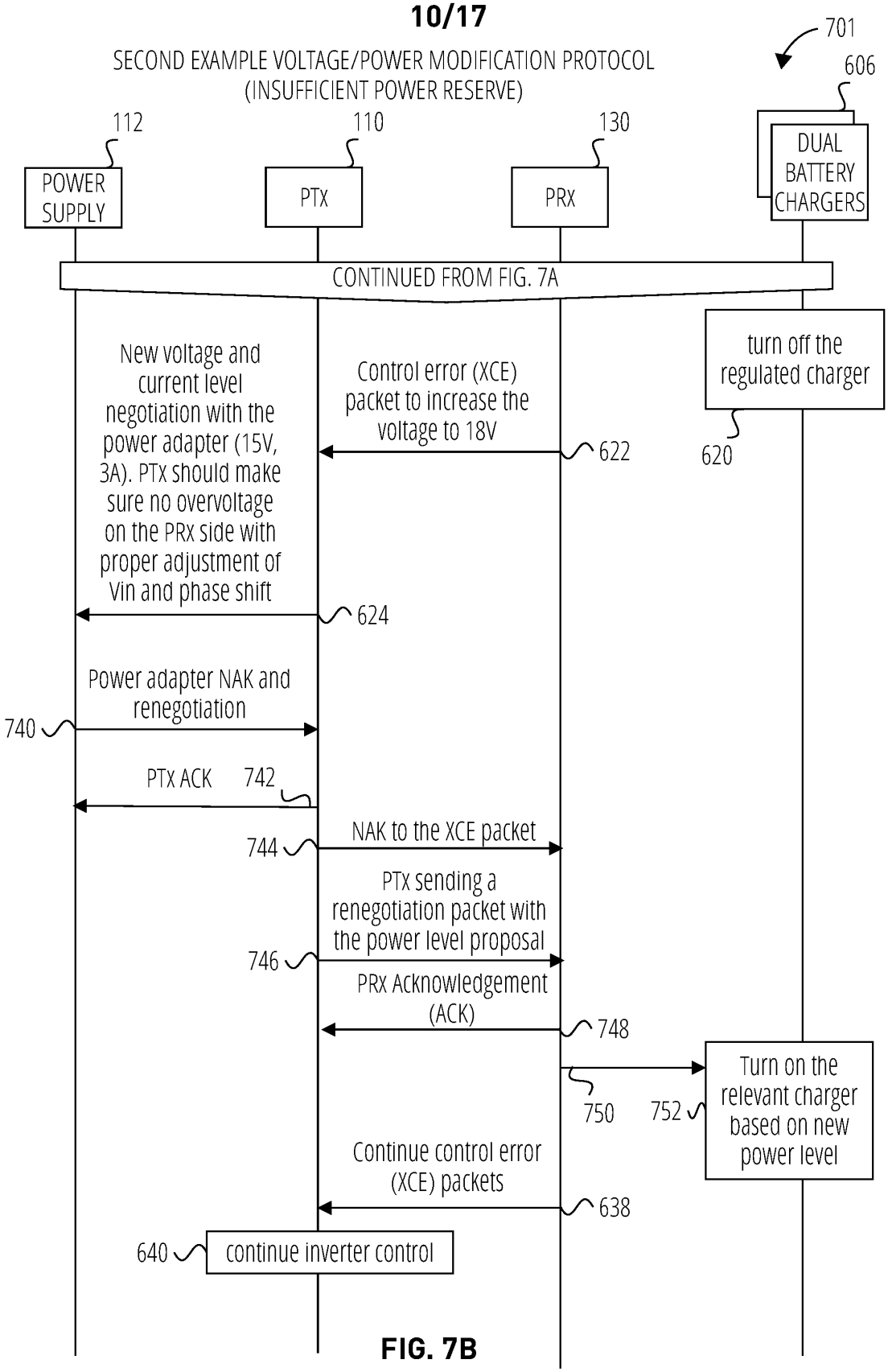
SECOND EXAMPLE VOLTAGE/POWER MODIFICATION PROTOCOL
(INSUFFICIENT POWER RESERVE)
701
606
112
110
130
POWER SUPPLY
PTx
PRx
DUAL BATTERY CHARGERS
CONTINUED FROM FIG. 7A
New voltage and current level negotiation with the power adapter (15V, 3A). PTx should make sure no overvoltage on the PRx side with proper adjustment of Vin and phase shift
624
Control error (XCE) packet to increase the voltage to 18V
622
turn off the regulated charger
620
Power adapter NAK and renegotiation
740
PTx ACK
742
NAK to the XCE packet
744
PTx sending a renegotiation packet with the power level proposal
746
PRx Acknowledgement (ACK)
748
750
752
Turn on the relevant charger based on new power level
Continue control error (XCE) packets
638
640
continue inverter control

FIG. 7B

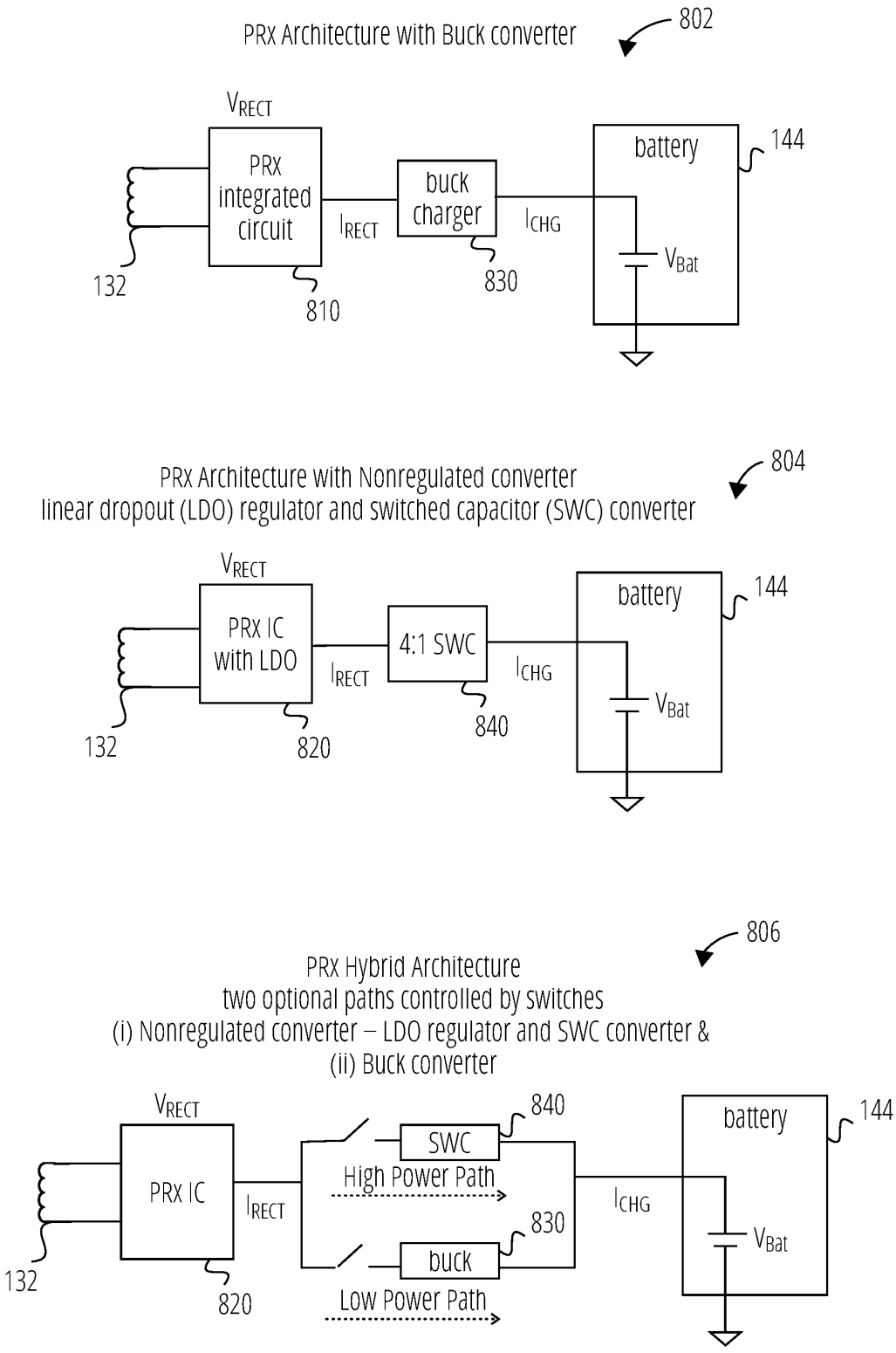
PRx Architecture with Buck converter
802
VRECT
PRx integrated circuit
IRECT
buck charger
ICHG
battery
144
VBat
132
810
830
PRx Architecture with Nonregulated converter
linear dropout (LDO) regulator and switched capacitor (SWC) converter
804
VRECT
PRx IC with LDO
IRECT
4:1 SWC
ICHG
battery
144
VBat
132
820
840
806
PRx Hybrid Architecture
two optional paths controlled by switches
(i) Nonregulated converter – LDO regulator and SWC converter &
(ii) Buck converter
VRECT
PRx IC
IRECT
840
SWC
High Power Path
830
buck
Low Power Path
ICHG
battery
144
VBat
132
820

FIG. 8

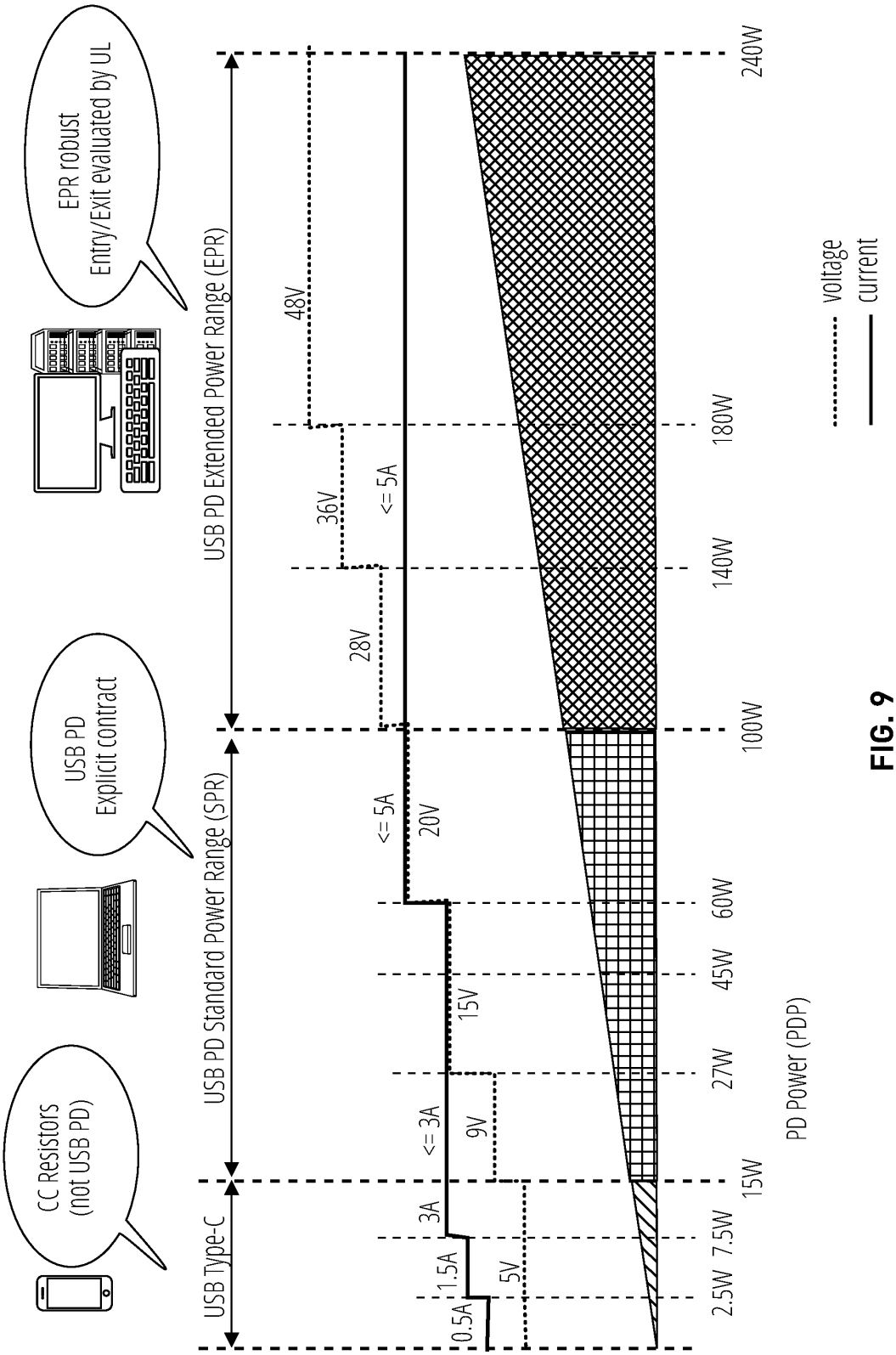
EPR robust
Entry/Exit evaluated by UL
USB PD
Explicit contract
CC Resistors
(not USB PD)
USB Type-C
USB PD Standard Power Range (SPR)
USB PD Extended Power Range (EPR)
5V
9V
15V
20V
28V
36V
48V
<= 3A
<= 5A
<= 5A
0.5A
1.5A
3A
15W
2.5W
7.5W
27W
45W
60W
100W
140W
180W
240W
PD Power (PDP)
voltage
current

FIG. 9

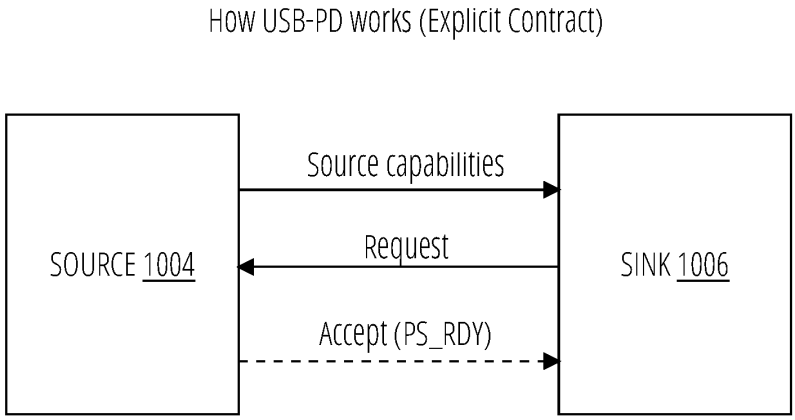
How USB-PD works (Explicit Contract)
SOURCE 1004
Source capabilities
Request
Accept (PS_RDY)
SINK 1006

FIG. 10

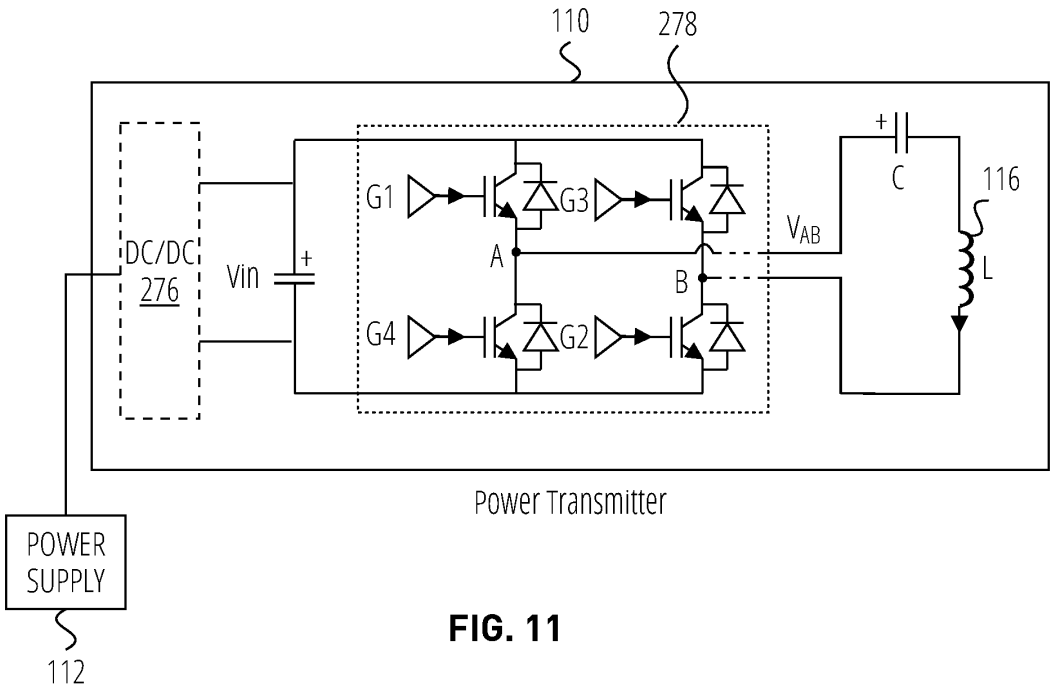
110
278
DC/DC
276
Vin
+
G1
G3
G4
G2
A
B
$V_{AB}$
+
C
116
L
Power Transmitter
POWER
SUPPLY
112

FIG. 11

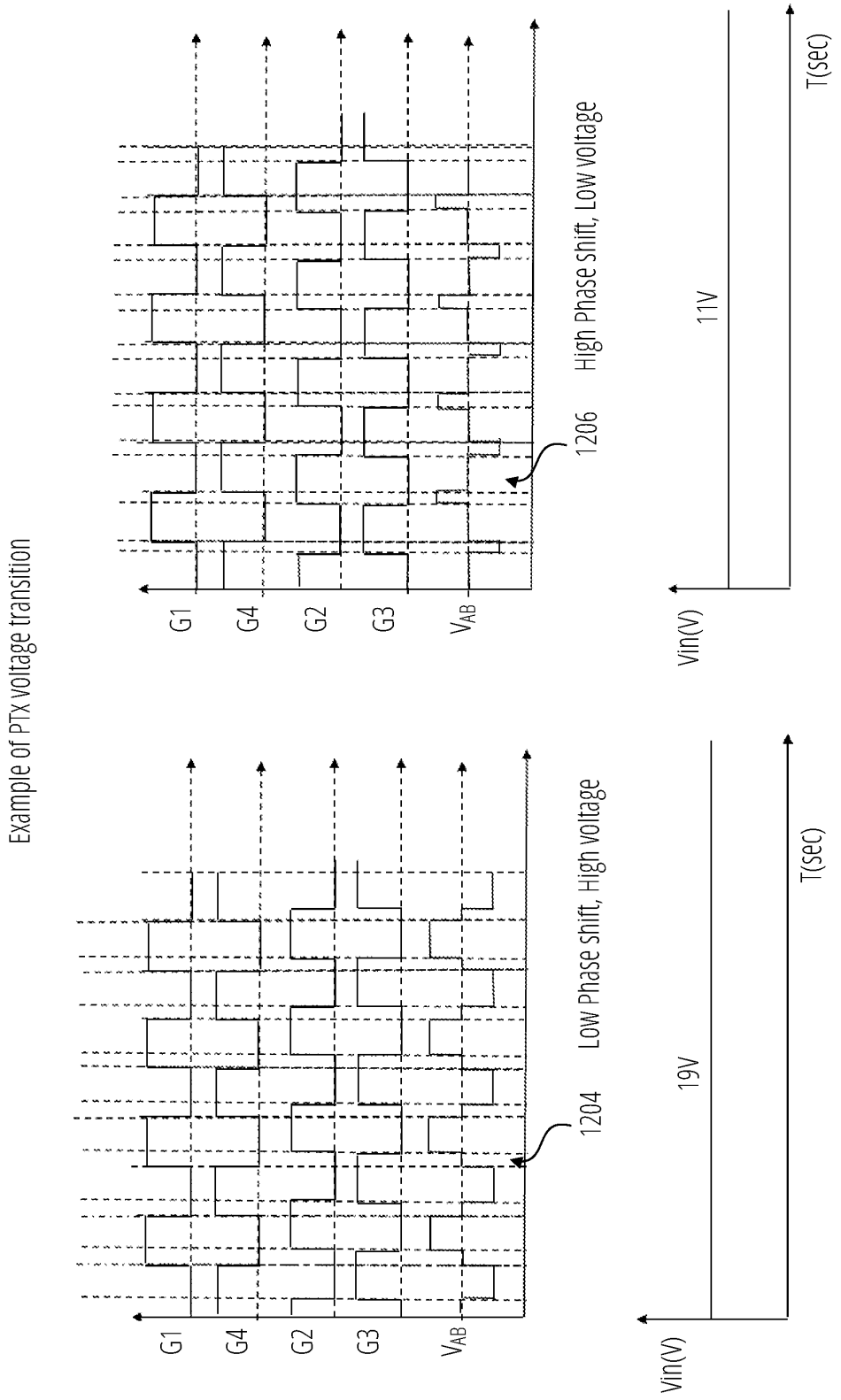
Example of PTx voltage transition
G1
G4
G2
G3
$V_{AB}$
1206
High Phase shift, LOW voltage
11V
Vin(V)
T(sec)
G1
G4
G2
G3
$V_{AB}$
1204
Low Phase shift, High voltage
19V
Vin(V)
T(sec)

FIG. 12

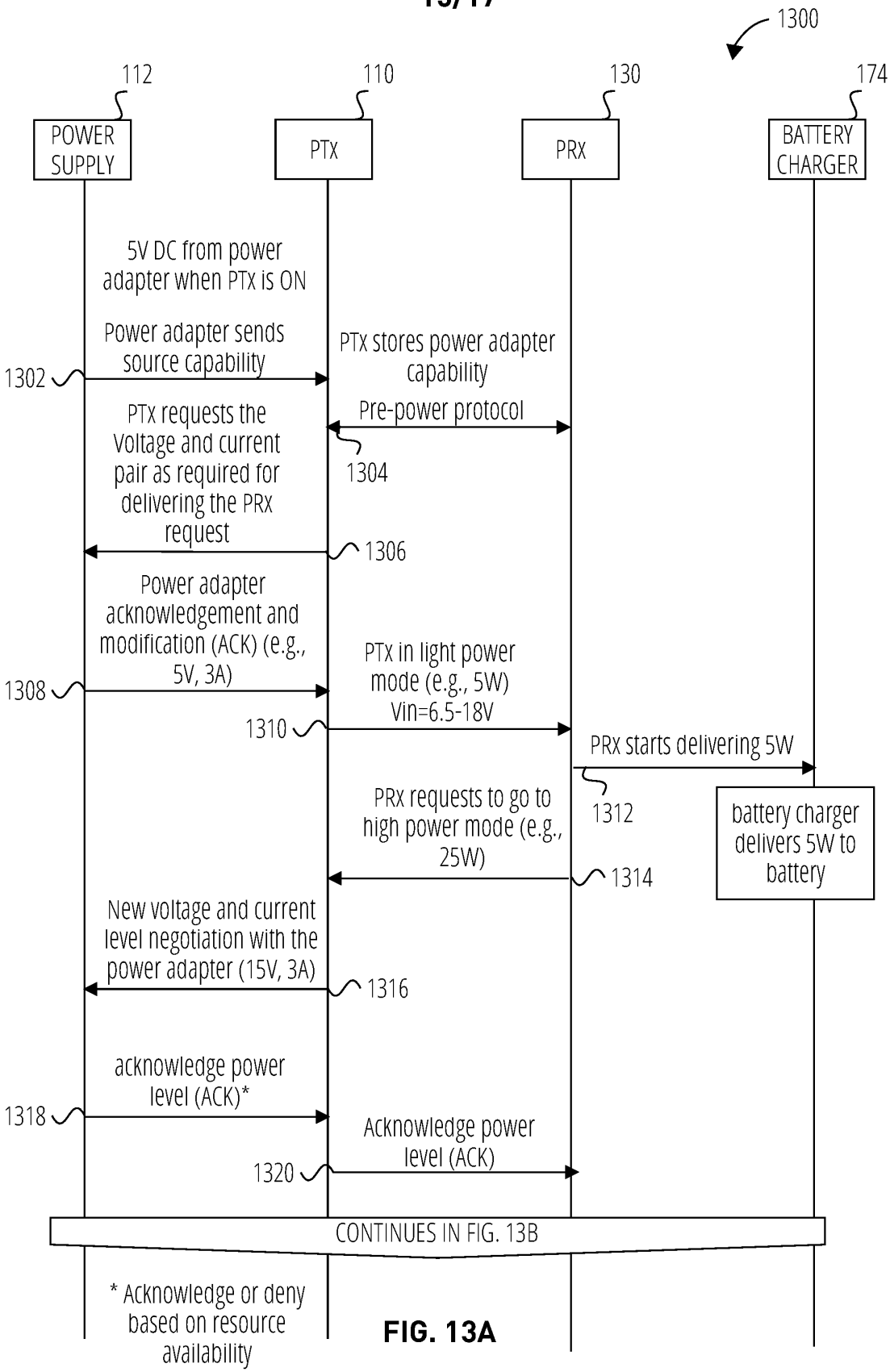
1300
112
110
130
174
POWER SUPPLY
PTx
PRx
BATTERY CHARGER
5V DC from power adapter when PTx is ON
Power adapter sends source capability
1302
PTx stores power adapter capability
Pre-power protocol
1304
PTx requests the Voltage and current pair as required for delivering the PRx request
1306
Power adapter acknowledgement and modification (ACK) (e.g., 5V, 3A)
1308
PTx in light power mode (e.g., 5W) Vin=6.5-18V
1310
PRx starts delivering 5W
1312
battery charger delivers 5W to battery
PRx requests to go to high power mode (e.g., 25W)
1314
New voltage and current level negotiation with the power adapter (15V, 3A)
1316
acknowledge power level (ACK)*
1318
Acknowledge power level (ACK)
1320
CONTINUES IN FIG. 13B
* Acknowledge or deny based on resource availability

FIG. 13A

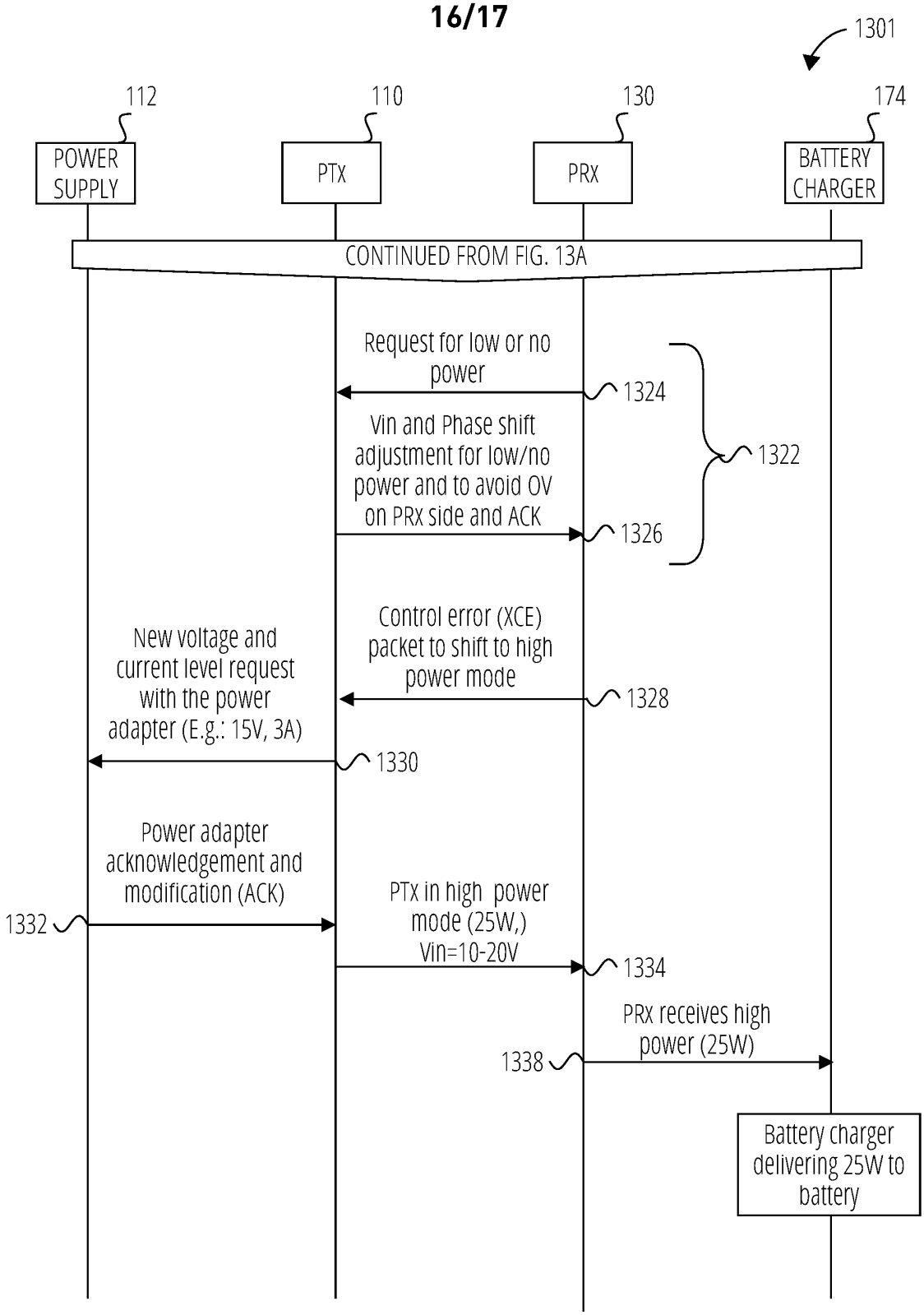
1301
112
110
130
174
POWER SUPPLY
PTx
PRx
BATTERY CHARGER
CONTINUED FROM FIG. 13A
Request for low or no power
1324
Vin and Phase shift adjustment for low/no power and to avoid OV on PRx side and ACK
1326
1322
Control error (XCE) packet to shift to high power mode
1328
New voltage and current level request with the power adapter (E.g.: 15V, 3A)
1330
Power adapter acknowledgement and modification (ACK)
1332
PTx in high power mode (25W,) Vin=10-20V
1334
PRx receives high power (25W)
1338
Battery charger delivering 25W to battery

FIG. 13B

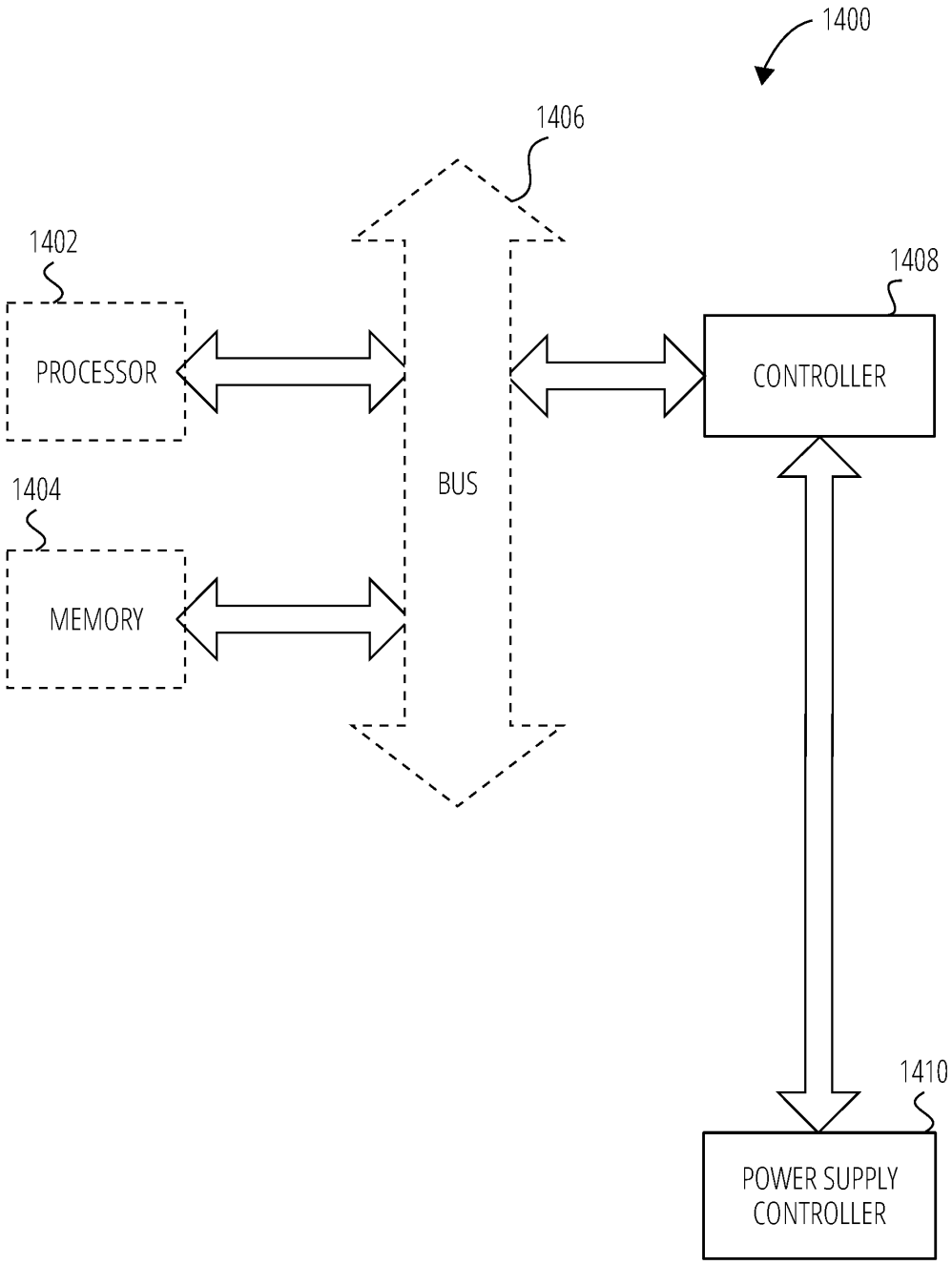
1400
1406
1402
1408
PROCESSOR
CONTROLLER
BUS
1404
MEMORY
1410
POWER SUPPLY CONTROLLER

FIG. 14