US012385981B2

(12) **United States Patent**
**Kitagawa**

(10) **Patent No.: US 12,385,981 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **BATTERY MONITORING DEVICE INCLUDING CALCULATION OF IMPEDANCE USING INDEPENDENT ELECTRICAL PATH TO A RESPONSE SIGNAL INPUT**

(71) Applicant: **DENSO CORPORATION**, Kariya (JP)

(72) Inventor: **Masaaki Kitagawa**, Kariya (JP)

(73) Assignee: **DENSO CORPORATION**, Kariya (JP)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 737 days.

(21) Appl. No.: **17/510,851**

(22) Filed: **Oct. 26, 2021**

(65) **Prior Publication Data**

US 2022/0045544 A1 Feb. 10, 2022

**Related U.S. Application Data**

(63) Continuation of application No. PCT/JP2020/017386, filed on Apr. 22, 2020.

(30) **Foreign Application Priority Data**

Apr. 26, 2019 (JP) ..... 2019-086141

(51) **Int. Cl.**
***G01R 31/389*** (2019.01)
***G01R 31/36*** (2020.01)
(Continued)

(52) **U.S. Cl.**
CPC ..... ***G01R 31/389*** (2019.01); ***G01R 31/3648*** (2013.01); ***G01R 31/367*** (2019.01);
(Continued)

(58) **Field of Classification Search**
CPC ..... G01R 31/389; G01R 31/3648; G01R 31/367; G01R 31/382; H01M 10/44;
(Continued)

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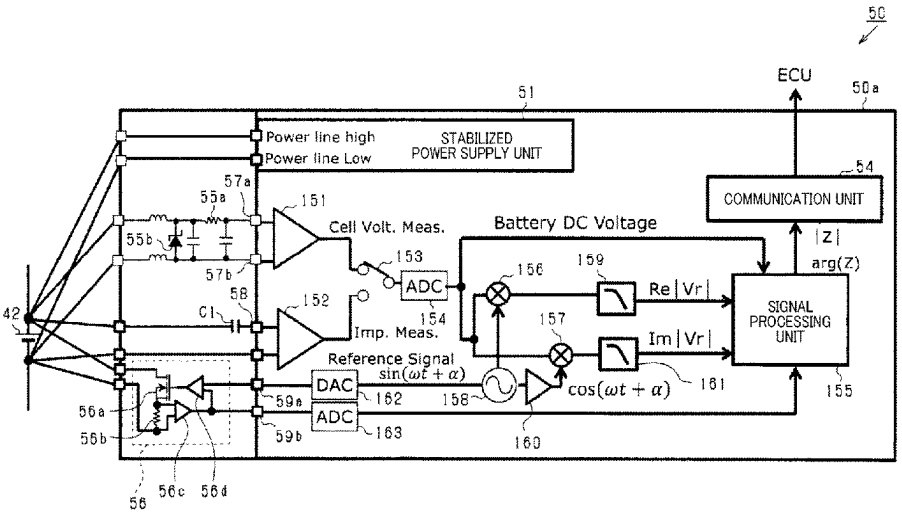
*Primary Examiner* — Richard Isla
*Assistant Examiner* — Manuel Hernandez
(74) *Attorney, Agent, or Firm* — Oliff PLC

(57) **ABSTRACT**

In a battery monitoring device for monitoring a state of a rechargeable battery that includes an electrolyte and a plurality of electrodes, a response signal input unit is configured to receive a response signal of the rechargeable battery to a predefined AC signal, and a calculation unit is configured to calculate a complex impedance of the rechargeable battery based on the response signal. A power supply unit is configured to receive a power supply voltage from the rechargeable battery and supplies the power supply voltage to at least the calculation unit. A first electrical path connecting the rechargeable battery to the power supply unit and a second electrical path connecting the rechargeable battery to the signal control unit are provided independent of each other. The signal control unit is configured to cause the rechargeable battery to be monitored, as a power source, to output the predefined AC signal.

**11 Claims, 13 Drawing Sheets**



(51) **Int. Cl.**

| | |
|---|---|
| ***G01R 31/367*** | (2019.01) |
| ***G01R 31/382*** | (2019.01) |
| ***H01M 10/44*** | (2006.01) |
| ***H01M 10/48*** | (2006.01) |
| ***H02J 7/00*** | (2006.01) |
| ***H02J 7/04*** | (2006.01) |

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

CPC ..... ***G01R 31/382*** (2019.01); ***H01M 10/44*** (2013.01); ***H01M 10/48*** (2013.01); ***H02J 7/0013*** (2013.01); ***H02J 7/0014*** (2013.01); ***H02J 7/0016*** (2013.01); ***H02J 7/0048*** (2020.01); ***H02J 7/005*** (2020.01); ***H02J 7/04*** (2013.01)

(58) **Field of Classification Search**

CPC ..... H01M 10/48; H02J 7/0013; H02J 7/0014; H02J 7/0016; H02J 7/0048; H02J 7/005; H02J 7/04

USPC ..... 702/63, 64, 65; 324/430; 320/135, 136

See application file for complete search history.

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FIG. 1

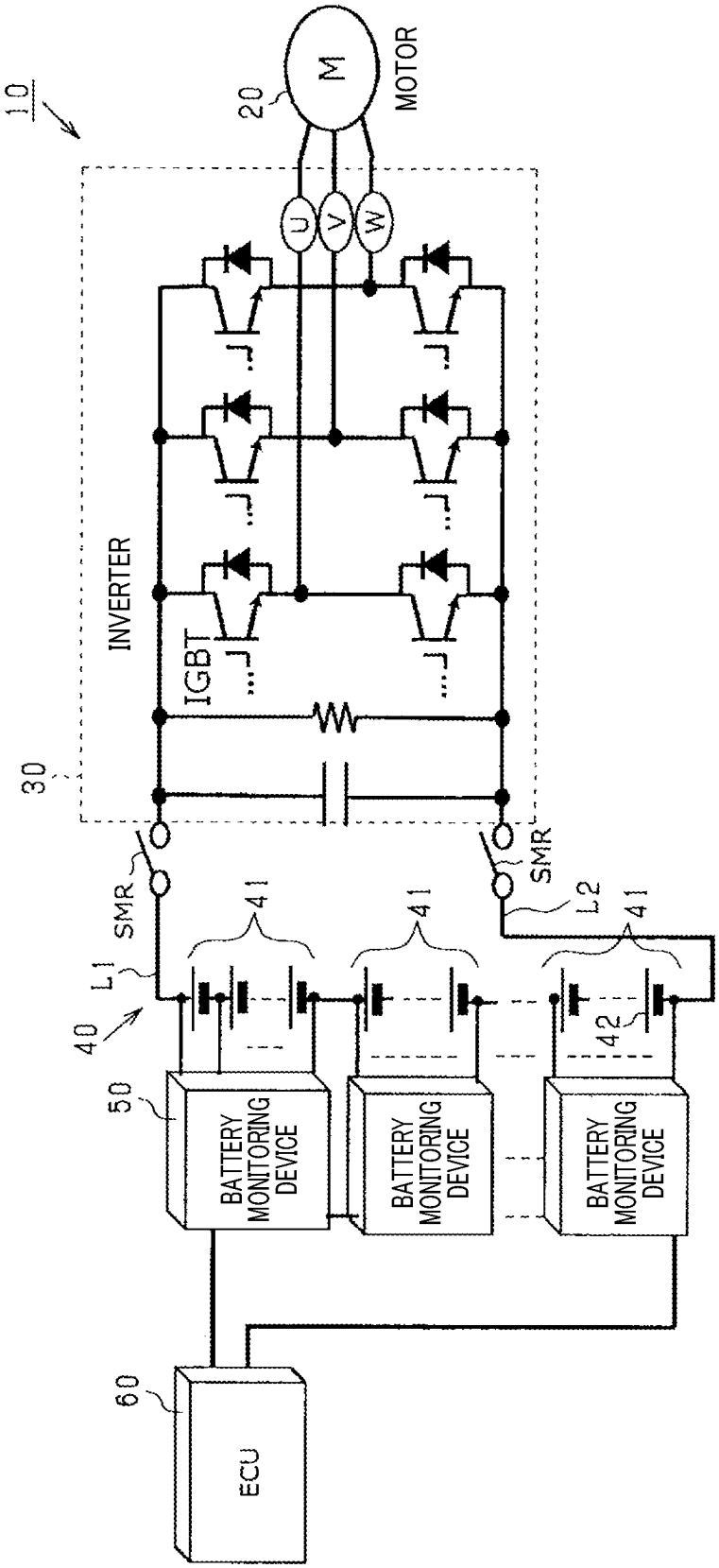

10
20
M
MOTOR
U
V
W
INVERTER
IGBT
30
SMR
SMR
L1
L2
41
41
41
42
40
50
BATTERY MONITORING DEVICE
BATTERY MONITORING DEVICE
BATTERY MONITORING DEVICE
60
ECU

FIG.2

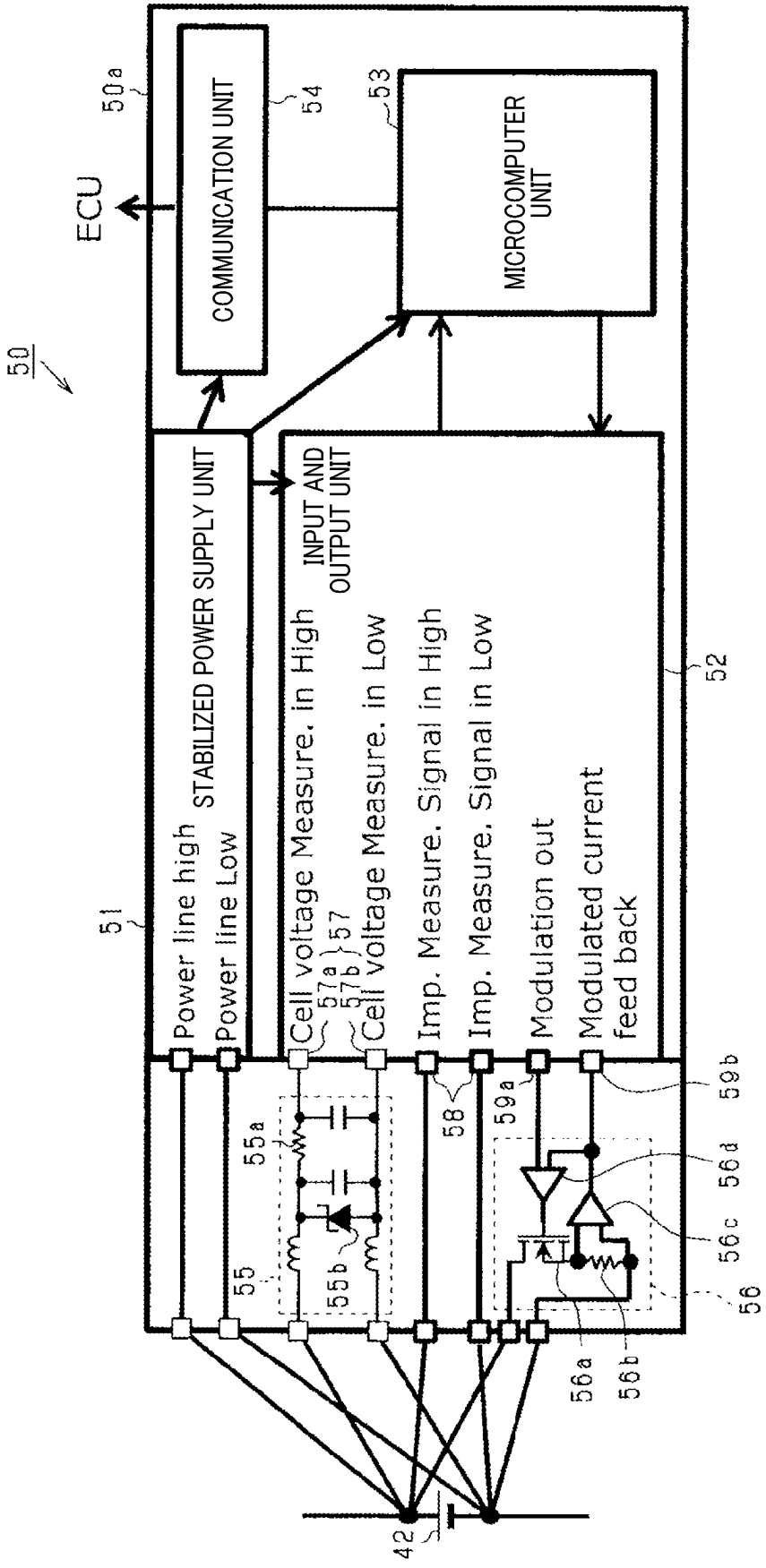

50
ECU
50a
COMMUNICATION UNIT
54
53
MICROCOMPUTER UNIT
STABILIZED POWER SUPPLY UNIT
INPUT AND OUTPUT UNIT
52
51
Power line high
Power line Low
Cell voltage Measure. in High
57a
Cell voltage Measure. in Low
57b
57
Imp. Measure. Signal in High
Imp. Measure. Signal in Low
Modulation out
Modulated current feed back
59b
59a
58
55a
55b
55
56d
56c
56
56a
56b
42

FIG.3

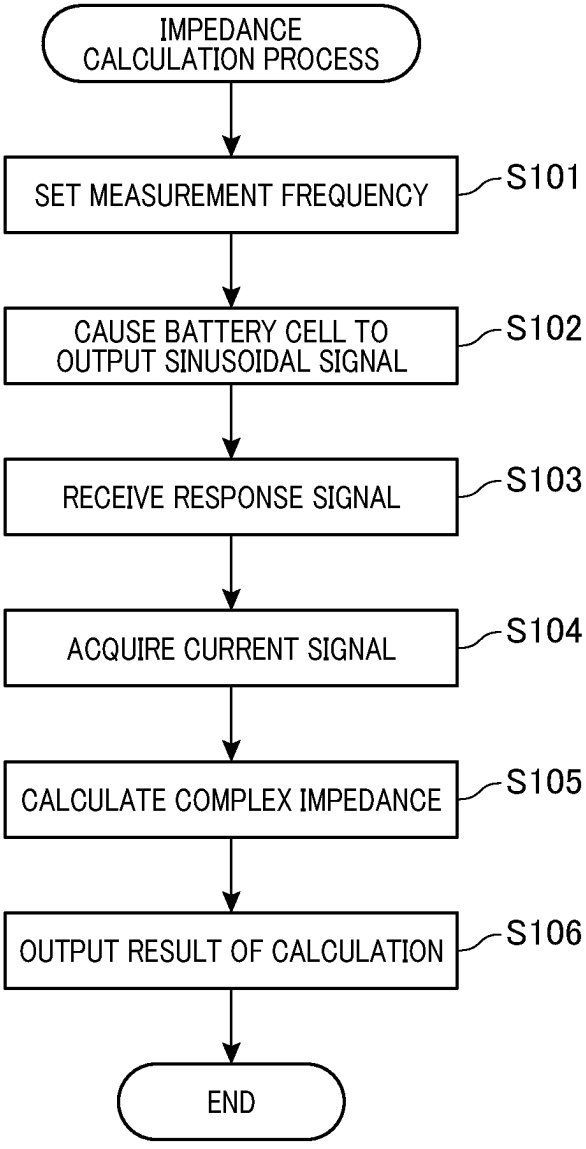

IMPEDANCE CALCULATION PROCESS
SET MEASUREMENT FREQUENCY
S101
CAUSE BATTERY CELL TO OUTPUT SINUSOIDAL SIGNAL
S102
RECEIVE RESPONSE SIGNAL
S103
ACQUIRE CURRENT SIGNAL
S104
CALCULATE COMPLEX IMPEDANCE
S105
OUTPUT RESULT OF CALCULATION
S106
END

FIG.4A

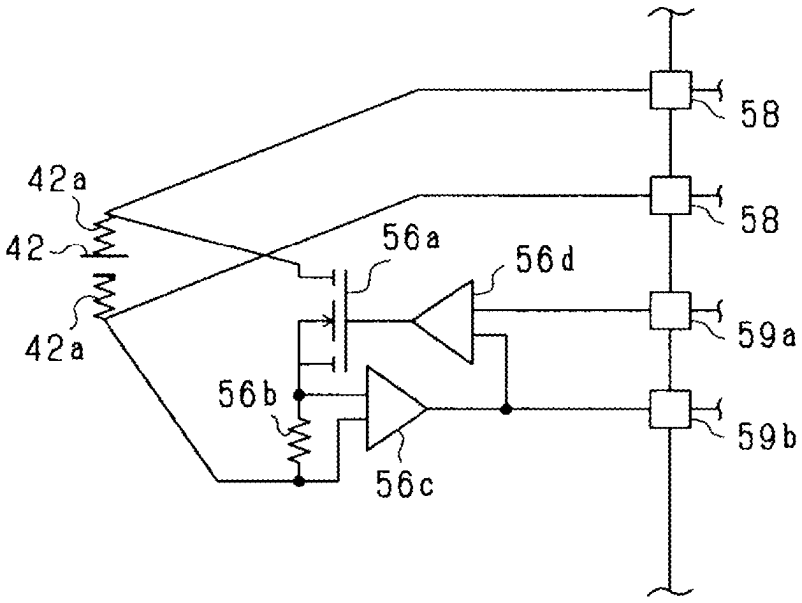

58
58
59a
59b
42a
42
42a
56a
56d
56b
56c

FIG.4B

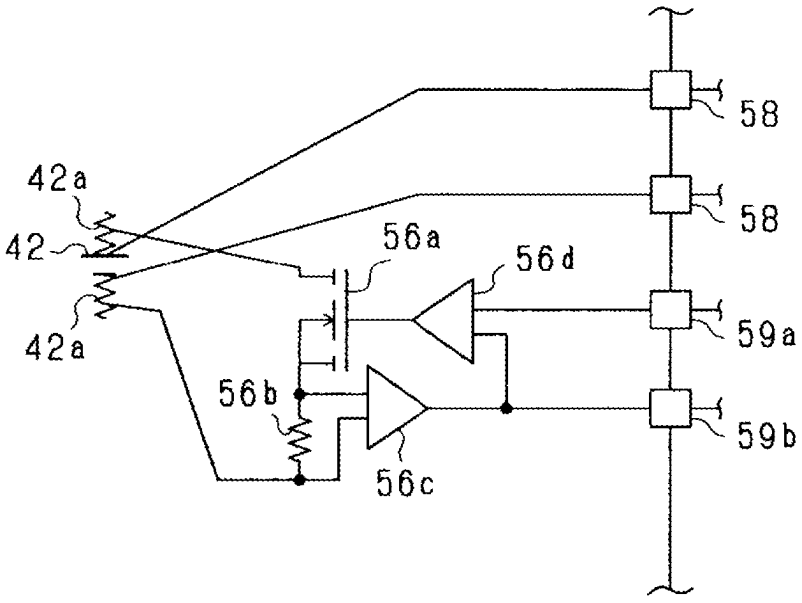

58
58
59a
59b
42a
42
42a
56a
56d
56b
56c

FIG.5

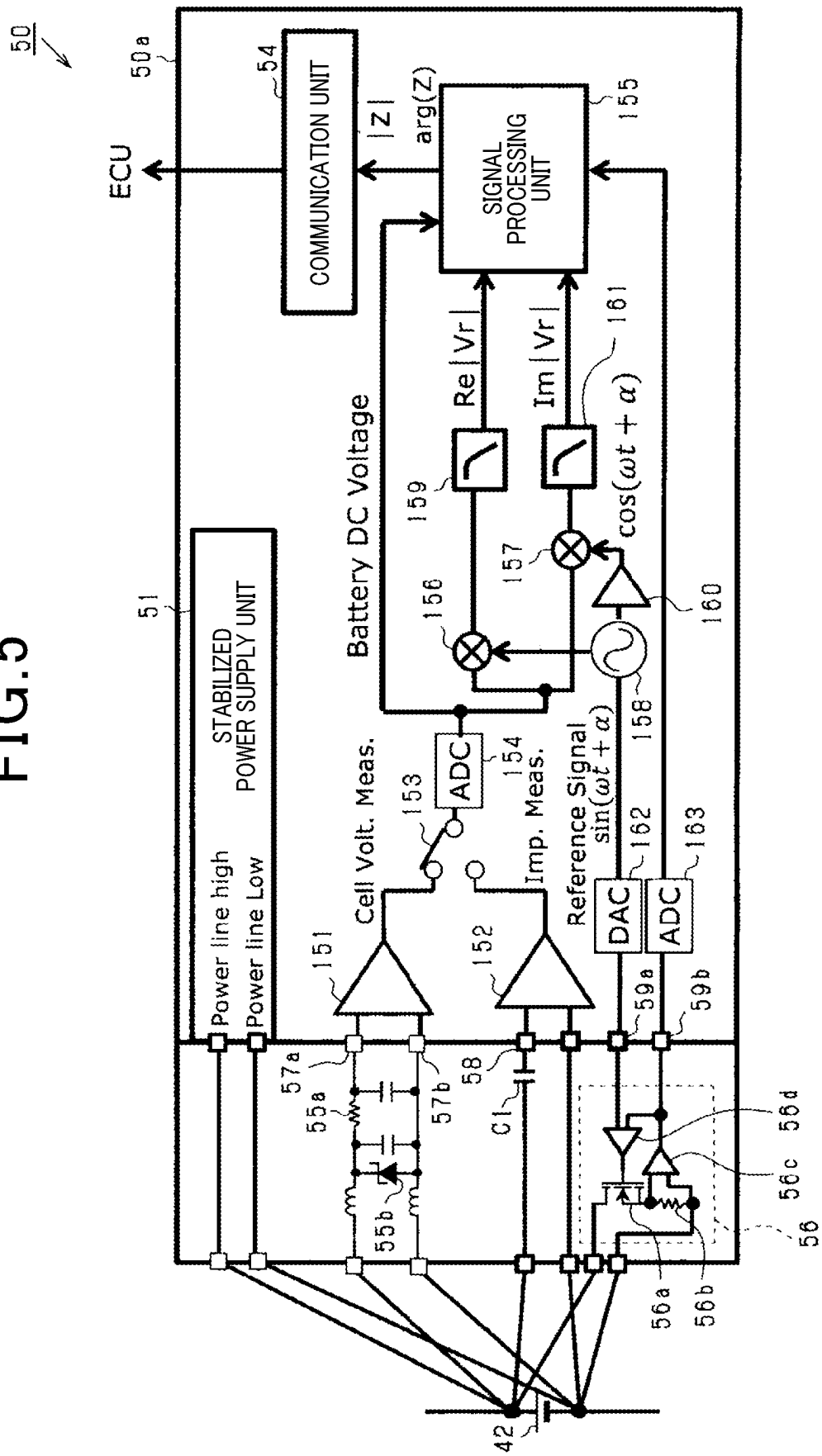

50
50a
ECU
54
COMMUNICATION UNIT
|Z|
arg(Z)
155
SIGNAL PROCESSING UNIT
51
STABILIZED POWER SUPPLY UNIT
Power line high
Power line Low
Battery DC Voltage
Re|Vr|
Im|Vr|
161
cos(ωt + α)
159
157
156
160
158
ADC
154
153
Cell Volt. Meas.
Imp. Meas.
Reference Signal sin(ωt + α)
162
163
DAC
ADC
151
152
59a
59b
57a
57b
58
55a
55b
C1
56d
56c
56
56a
56b
42

FIG.6

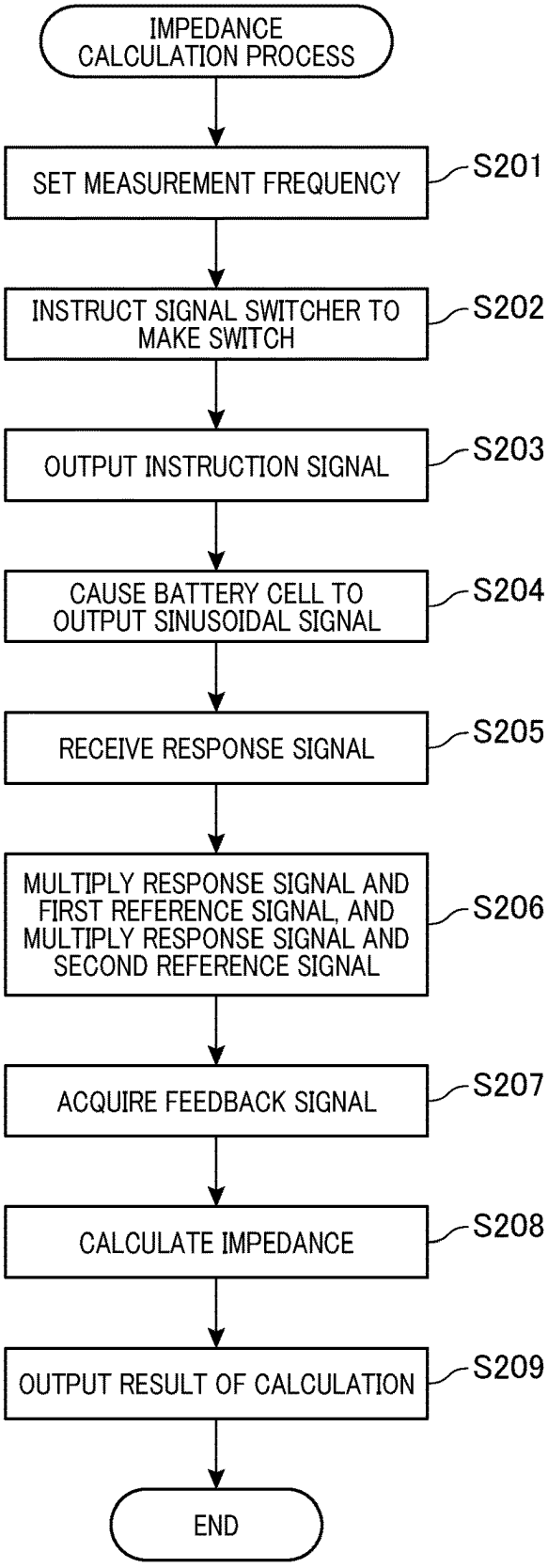
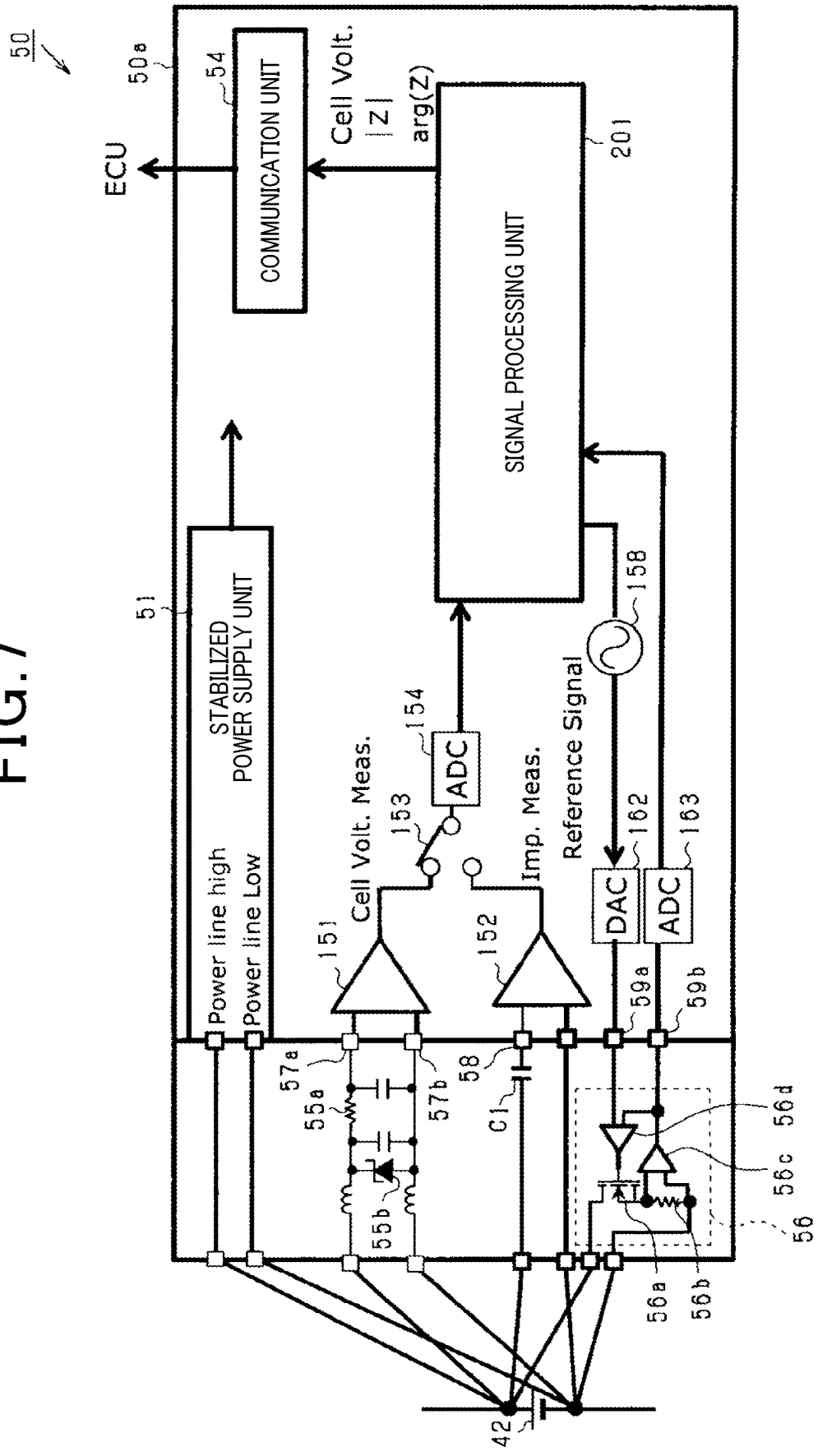

IMPEDANCE CALCULATION PROCESS
SET MEASUREMENT FREQUENCY
S201
INSTRUCT SIGNAL SWITCHER TO MAKE SWITCH
S202
OUTPUT INSTRUCTION SIGNAL
S203
CAUSE BATTERY CELL TO OUTPUT SINUSOIDAL SIGNAL
S204
RECEIVE RESPONSE SIGNAL
S205
MULTIPLY RESPONSE SIGNAL AND FIRST REFERENCE SIGNAL, AND MULTIPLY RESPONSE SIGNAL AND SECOND REFERENCE SIGNAL
S206
ACQUIRE FEEDBACK SIGNAL
S207
CALCULATE IMPEDANCE
S208
OUTPUT RESULT OF CALCULATION
S209
END

FIG. 7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50a
54
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ECU
Cell Volt.
|Z|
arg(Z)
201
SIGNAL PROCESSING UNIT
51
STABILIZED
POWER SUPPLY UNIT
Power line high
Power line Low
158
Reference Signal
154
ADC
153
Cell Volt. Meas.
Imp. Meas.
151
152
DAC
162
ADC
163
59a
59b
57a
55a
57b
58
C1
56d
56c
56
55b
56a
56b
42

FIG.8

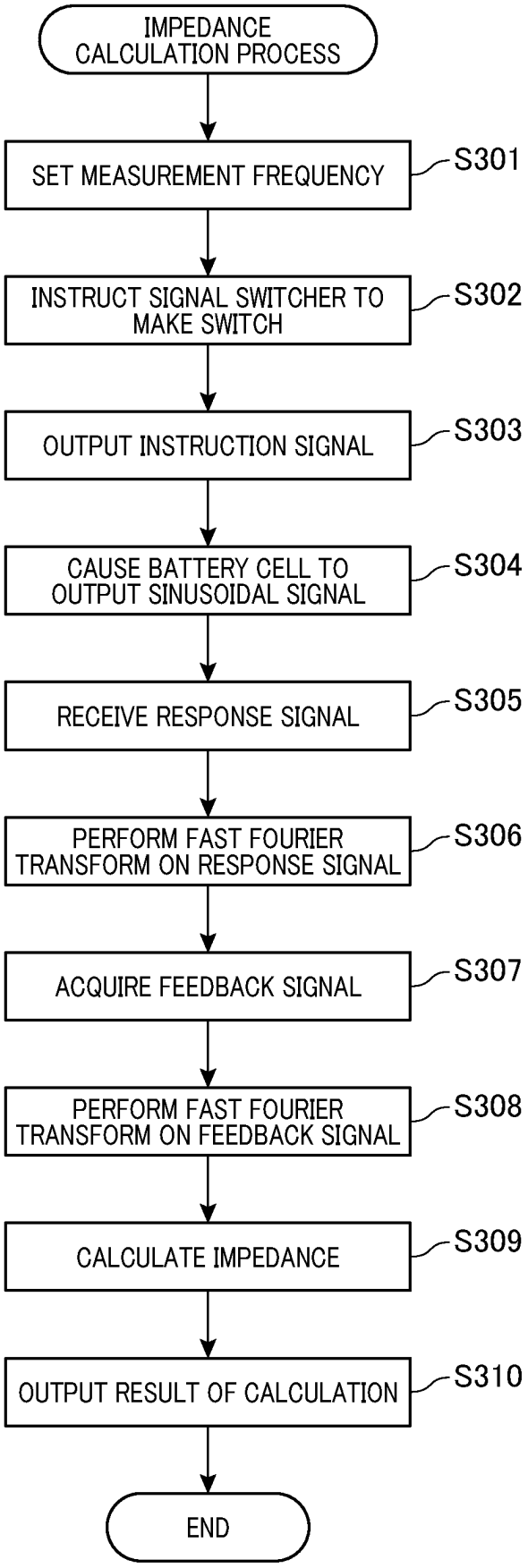
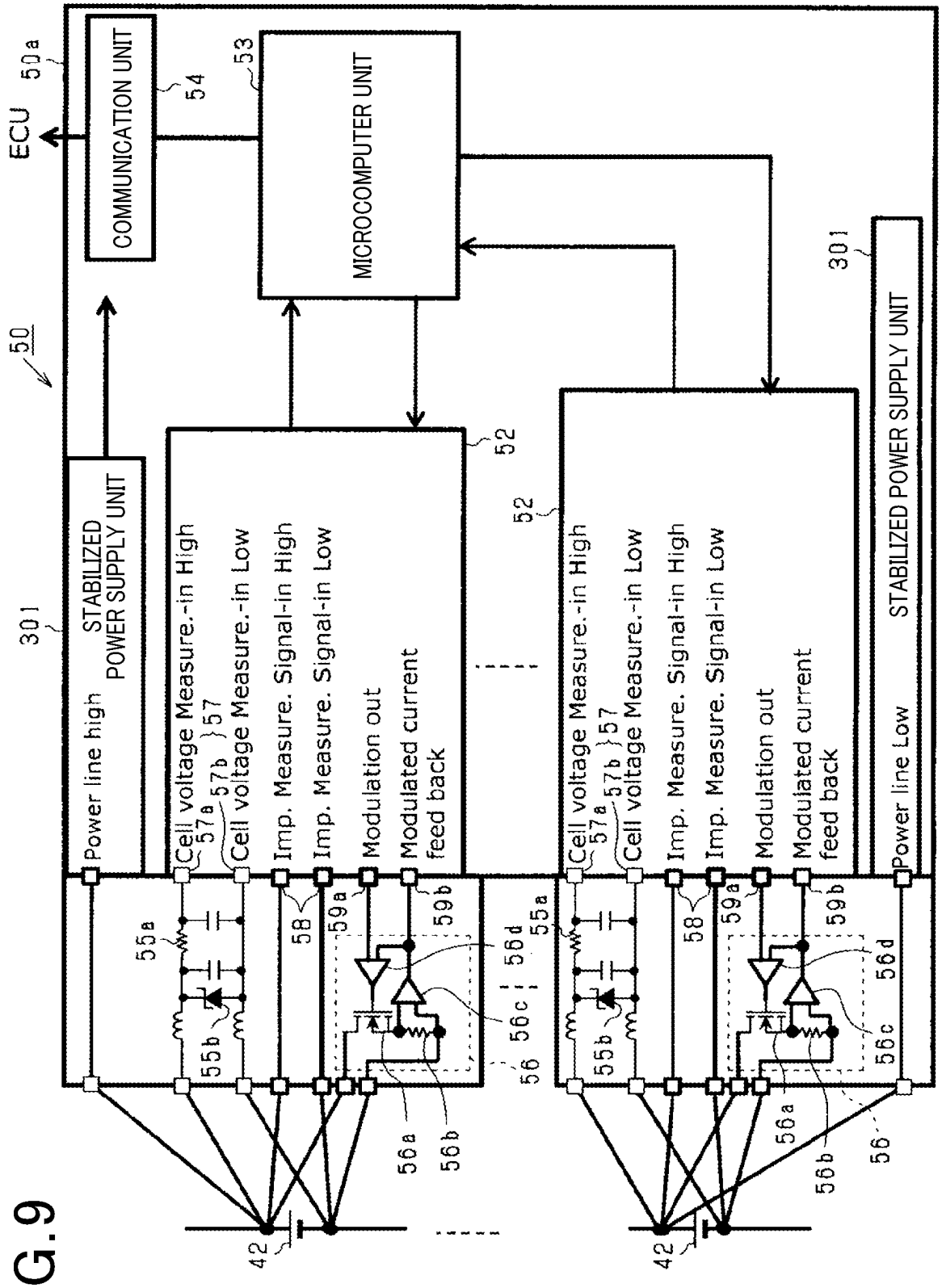

IMPEDANCE CALCULATION PROCESS
SET MEASUREMENT FREQUENCY
S301
INSTRUCT SIGNAL SWITCHER TO MAKE SWITCH
S302
OUTPUT INSTRUCTION SIGNAL
S303
CAUSE BATTERY CELL TO OUTPUT SINUSOIDAL SIGNAL
S304
RECEIVE RESPONSE SIGNAL
S305
PERFORM FAST FOURIER TRANSFORM ON RESPONSE SIGNAL
S306
ACQUIRE FEEDBACK SIGNAL
S307
PERFORM FAST FOURIER TRANSFORM ON FEEDBACK SIGNAL
S308
CALCULATE IMPEDANCE
S309
OUTPUT RESULT OF CALCULATION
S310
END

FIG.9


ECU
50a
COMMUNICATION UNIT
54
53
MICROCOMPUTER UNIT
50
301
STABILIZED POWER SUPPLY UNIT
Power line high
52
Cell voltage Measure.-in High
57a
Cell voltage Measure.-in Low
57b
57
Imp. Measure. Signal-in High
Imp. Measure. Signal-in Low
Modulation out
Modulated current feed back
59b
58
59a
55a
55b
56d
56c
56
56a
56b
42
301
STABILIZED POWER SUPPLY UNIT
Power line Low

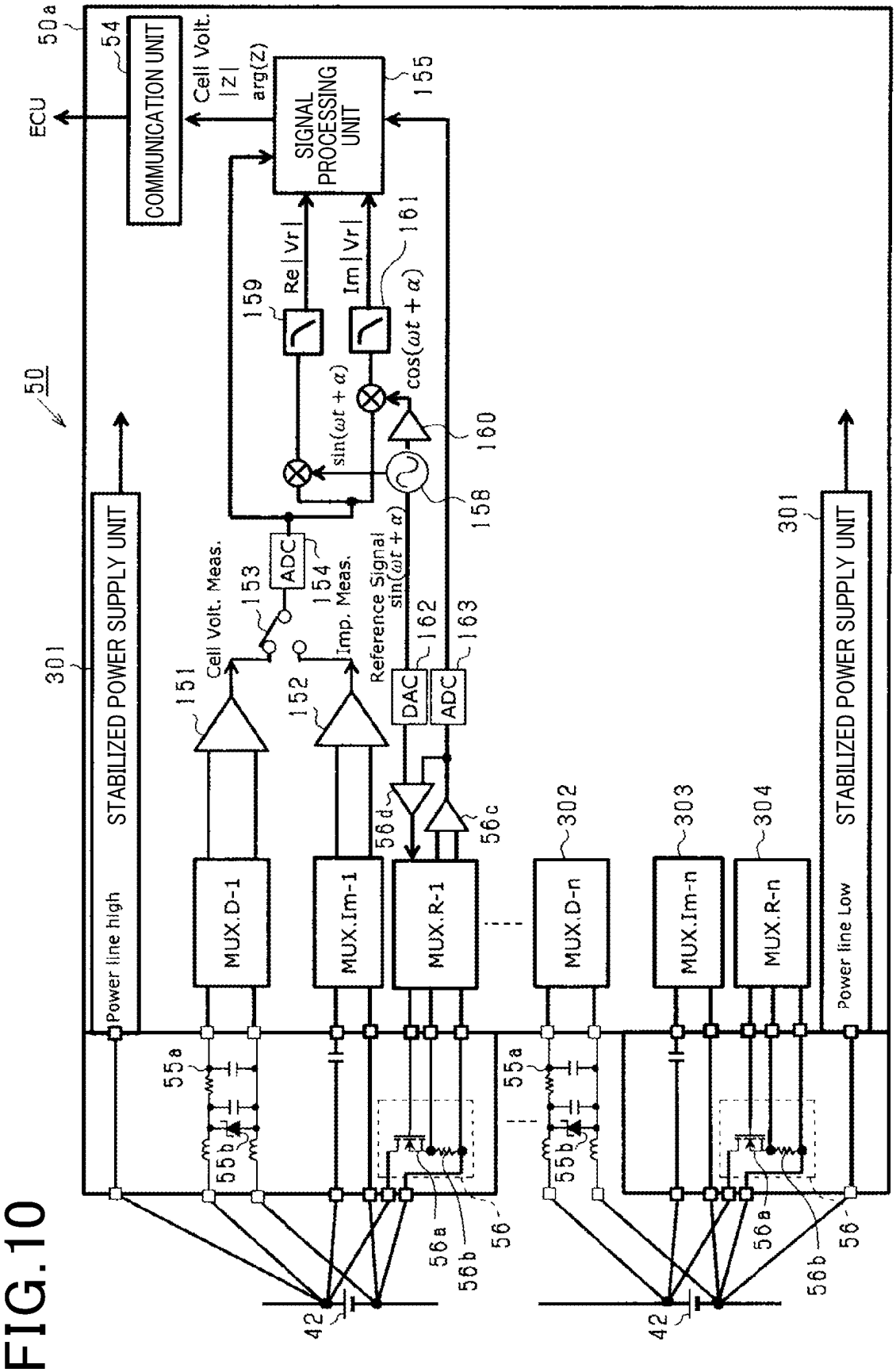

50
50a
54
COMMUNICATION UNIT
ECU
Cell Volt.
|Z|
arg(Z)
SIGNAL PROCESSING UNIT
155
159
Re|Vr|
Im|Vr|
161
$\cos(\omega t+\alpha)$
$\sin(\omega t+\alpha)$
160
158
Reference Signal $\sin(\omega t+\alpha)$
301
STABILIZED POWER SUPPLY UNIT
Power line high
Cell Volt. Meas.
153
ADC
154
Imp. Meas.
151
152
DAC
162
ADC
163
56d
56c
MUX.D-1
MUX.Im-1
MUX.R-1
MUX.D-n
MUX.Im-n
MUX.R-n
302
303
304
Power line Low
55a
55b
56a
56b
56
42

FIG.10

FIG.11

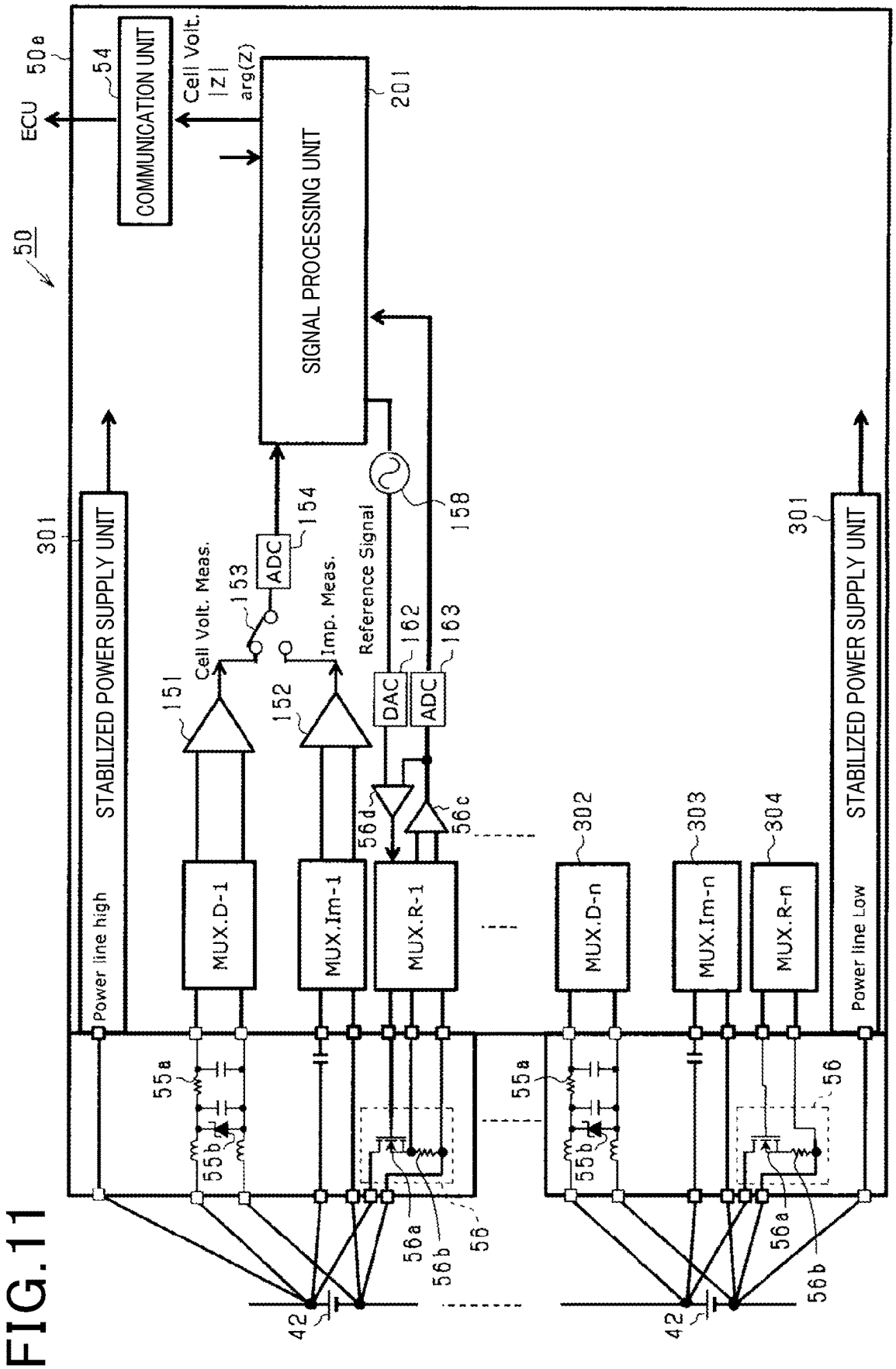

50
ECU
50a
54
COMMUNICATION UNIT
Cell Volt.
|Z|
arg(Z)
201
SIGNAL PROCESSING UNIT
301
STABILIZED POWER SUPPLY UNIT
Power line high
Power line Low
154
ADC
153
Cell Volt. Meas.
Imp. Meas.
Reference Signal
158
162
DAC
163
ADC
151
152
56d
56c
MUX.D-1
MUX.Im-1
MUX.R-1
302
MUX.D-n
303
MUX.Im-n
304
MUX.R-n
55a
55b
56
56a
56b
42

FIG.12

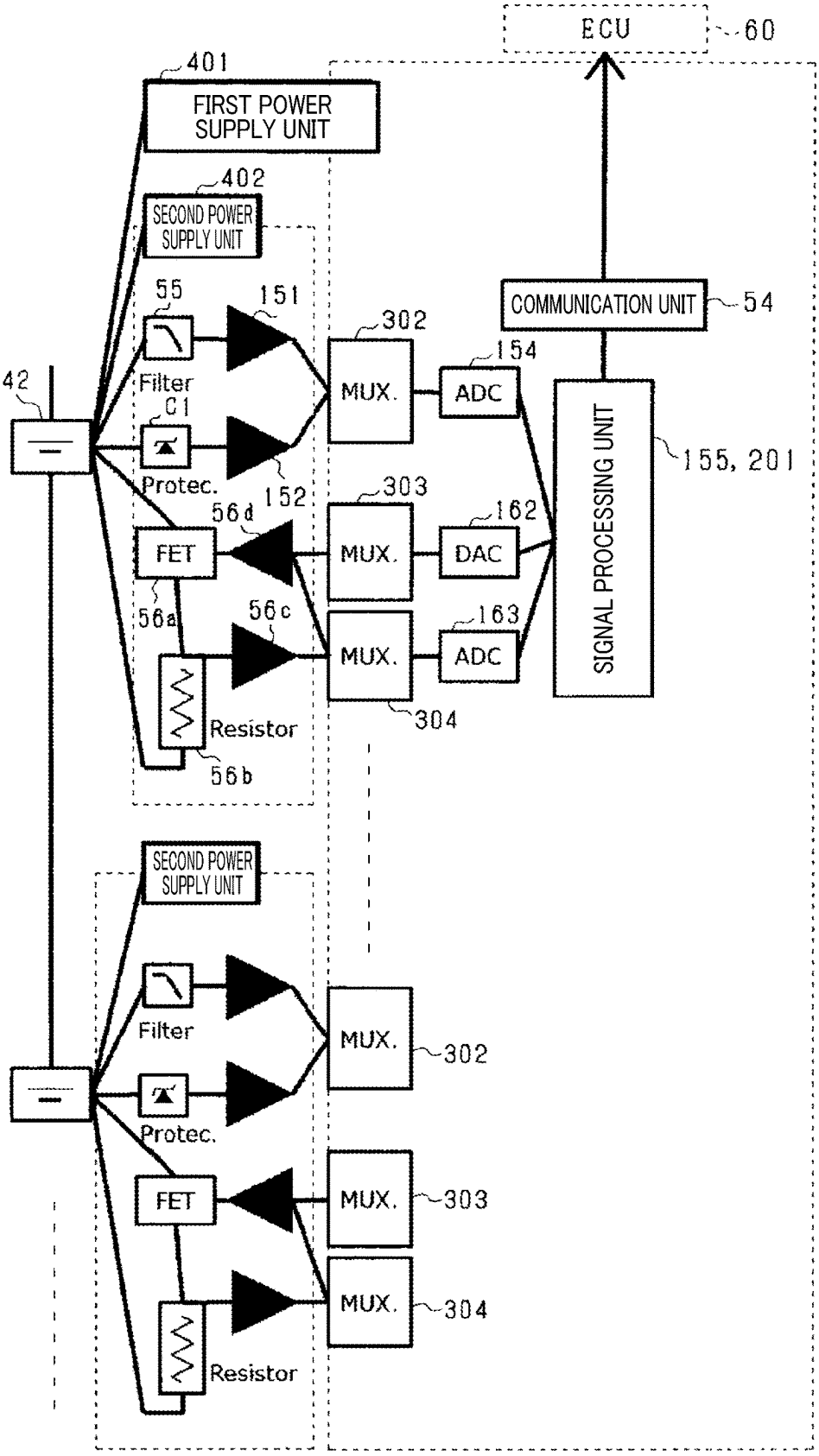
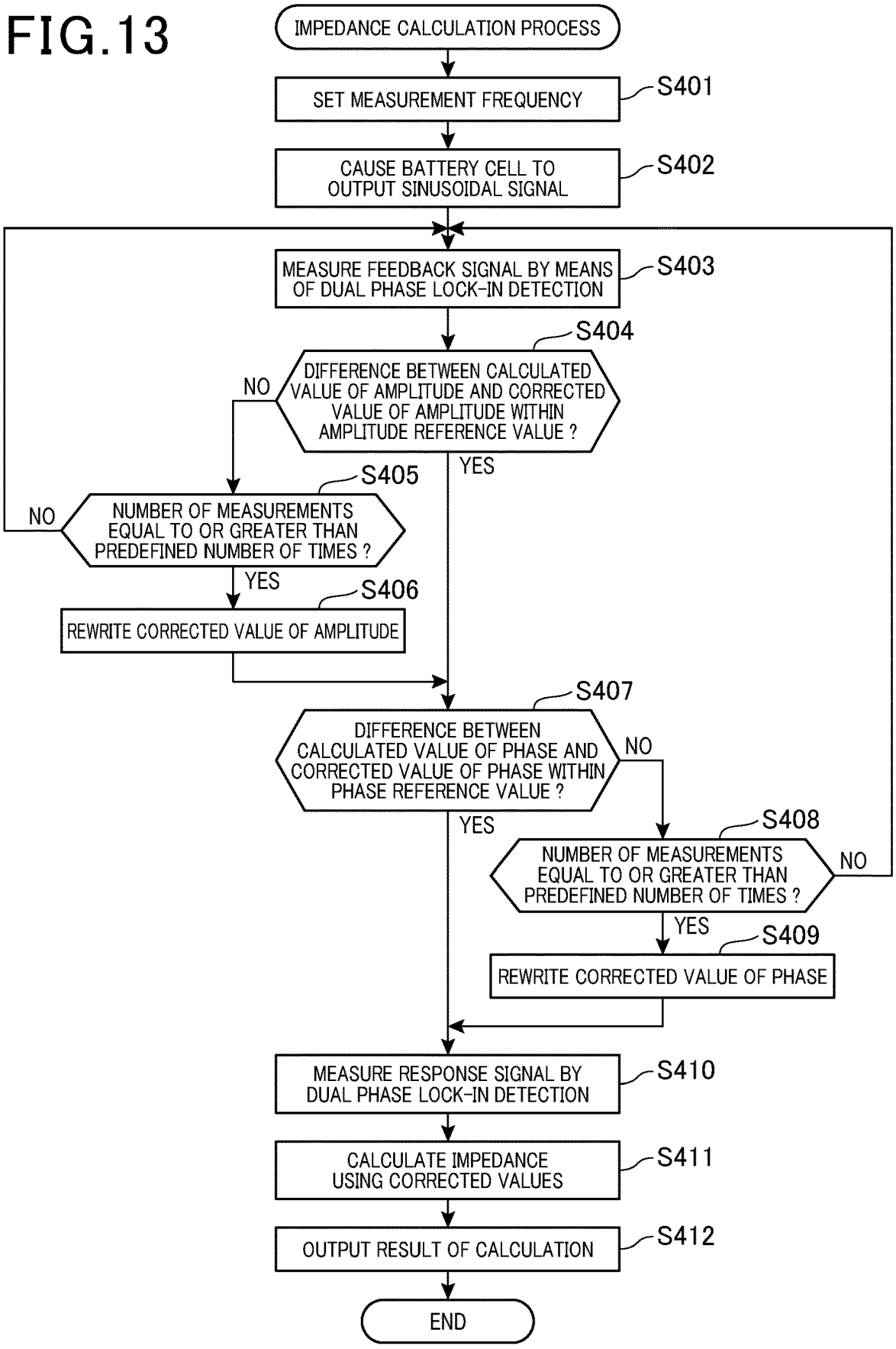

ECU
60
401
FIRST POWER SUPPLY UNIT
402
SECOND POWER SUPPLY UNIT
55
151
Filter
C1
Protec.
152
42
302
MUX.
154
ADC
COMMUNICATION UNIT
54
SIGNAL PROCESSING UNIT
155, 201
303
MUX.
162
DAC
56d
FET
56a
56c
MUX.
163
ADC
Resistor
56b
304
SECOND POWER SUPPLY UNIT
Filter
Protec.
MUX.
302
FET
MUX.
303
Resistor
MUX.
304

FIG.13


IMPEDANCE CALCULATION PROCESS
SET MEASUREMENT FREQUENCY
S401
CAUSE BATTERY CELL TO OUTPUT SINUSOIDAL SIGNAL
S402
MEASURE FEEDBACK SIGNAL BY MEANS OF DUAL PHASE LOCK-IN DETECTION
S403
S404
DIFFERENCE BETWEEN CALCULATED VALUE OF AMPLITUDE AND CORRECTED VALUE OF AMPLITUDE WITHIN AMPLITUDE REFERENCE VALUE ?
NO
YES
S405
NUMBER OF MEASUREMENTS EQUAL TO OR GREATER THAN PREDEFINED NUMBER OF TIMES ?
NO
YES
S406
REWRITE CORRECTED VALUE OF AMPLITUDE
S407
DIFFERENCE BETWEEN CALCULATED VALUE OF PHASE AND CORRECTED VALUE OF PHASE WITHIN PHASE REFERENCE VALUE ?
NO
YES
S408
NUMBER OF MEASUREMENTS EQUAL TO OR GREATER THAN PREDEFINED NUMBER OF TIMES ?
NO
YES
S409
REWRITE CORRECTED VALUE OF PHASE
MEASURE RESPONSE SIGNAL BY DUAL PHASE LOCK-IN DETECTION
S410
CALCULATE IMPEDANCE USING CORRECTED VALUES
S411
OUTPUT RESULT OF CALCULATION
S412
END

# BATTERY MONITORING DEVICE INCLUDING CALCULATION OF IMPEDANCE USING INDEPENDENT ELECTRICAL PATH TO A RESPONSE SIGNAL INPUT

## CROSS-REFERENCE TO RELATED APPLICATION

This application is based on and claims the benefit of priority from earlier Japanese Patent Application No. 2019-086141 filed Apr. 26, 2019, the description of which is incorporated herein by reference.

## BACKGROUND

### Technical Field

The present disclosure relates to a battery monitoring device.

### Related Art

Conventionally, the complex impedance of a rechargeable battery is measured in order to monitor the state of the rechargeable battery. In a known technique, a square wave signal is applied to the rechargeable battery by a power controller, and the complex impedance characteristics are calculated based on a response signal thereto. The complex impedance characteristics are then used to determine a deterioration condition of the rechargeable battery.

## BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a schematic diagram of a power supply system;

FIG. **2** is a schematic diagram of a battery monitoring device;

FIG. **3** is a flowchart of a complex impedance calculation process;

FIG. **4**A is an illustration of connection points;

FIG. **4**B is an illustration of connection points;

FIG. **5** is a schematic diagram of a battery monitoring device according to a second embodiment;

FIG. **6** is a flowchart of a complex impedance calculation process of the second embodiment;

FIG. **7** is a schematic diagram of a battery monitoring device according to a third embodiment;

FIG. **8** is a flowchart of a complex impedance calculation process of the third embodiment;

FIG. **9** is a schematic diagram of a battery monitoring device according to another embodiment;

FIG. **10** is a schematic diagram of a battery monitoring device according to another embodiment;

FIG. **11** is a schematic diagram of a battery monitoring device according to another embodiment;

FIG. **12** is a schematic diagram of a battery monitoring device according to another embodiment; and

FIG. **13** is a flowchart of a complex impedance calculation process of another embodiment.

## DESCRIPTION OF SPECIFIC EMBODIMENTS

According to the above known technique, as disclosed in JP6226261 B2, adoption of the above complex impedance measurement method as a complex impedance measurement method for vehicle rechargeable batteries may give rise to the following issue. That is, a device for applying signals to the rechargeable battery, such as a power controller or the like, is required, which leads to increased size and cost of the battery monitoring device.



In view of the foregoing, it is desired to have a battery monitoring device that can be miniaturized.

One aspect of the present disclosure provides a battery monitoring device for monitoring a state of a rechargeable battery that includes an electrolyte and a plurality of electrodes, including: a signal control unit configured to instruct emission of a predefined AC signal; a response signal input unit configured to receive a response signal of the rechargeable battery to the AC signal; a calculation unit configured to calculate a complex impedance of the rechargeable battery based on the response signal; and a power supply unit configured to receive a power supply voltage from the rechargeable battery and supplies the power supply voltage to at least the calculation unit. In the battery monitoring device, a first electrical path connecting the rechargeable battery to the power supply unit and a second electrical path connecting the rechargeable battery to the signal control unit are provided independent of each other, and the signal control unit is configured to cause the rechargeable battery to be monitored, as a power source, to output the predefined AC signal.

With the above configuration, the signal control unit causes the rechargeable battery to be monitored, as a power source, to output the sinusoidal signal (the predefined alternating current (AC) signal). This eliminates the need for an external power source for inputting the sinusoidal signal to the battery cell, leading to a reduced number of parts, downsizing, and reduced costs.

Typically, the rechargeable battery for a vehicle is connected to peripheral circuits, such as protection elements and filter circuits. Even when an AC signal is input to the rechargeable battery, a portion of the current may leak into these peripheral circuits. Thus, there has been an issue that, when inputting the AC signal to the rechargeable battery and calculating the complex impedance based on the response signal thereto, errors in the response signal may occur due to the effect of the leakage current, leading to reduced accuracy of the complex impedance.

With the above configuration, the rechargeable battery is used as a power source to output the AC signal, which enables implementation of a closed circuit formed of the current modulation circuit and the rechargeable battery. Therefore, the leakage of the current from the rechargeable battery to the peripheral circuits can be eliminated, and the errors in the response signal can be suppressed.

Hereinafter, some embodiments of the disclosure will be described with reference to the accompanying drawings.

### First Embodiment

A first embodiment in which a "battery monitoring device" is applied to a power supply system of a vehicle (e.g., a hybrid vehicle or an electric vehicle) will now be described with reference to the accompanying drawings.

As illustrated in FIG. **1**, the power supply system **10** includes a motor **20** as a rotary electric machine, an inverter **30** as a power converter that conducts three-phase currents to the motor **20**, an assembled battery **40** that can be charged and discharged, a battery monitoring device **50** that monitors the state of the assembled battery **40**, and an electronic control unit (ECU) **60** that controls the motor **20** and the like.

The motor **20** is a vehicle prime mover and capable of transmitting power to drive wheels (not shown). In the

present embodiment, a three-phase permanent magnet synchronous motor is used as the motor **20**.

The inverter **30** is formed of a full bridge circuit having the same number of pairs of upper and lower arms as the number of phases of the phase windings, and the current flowing through each phase winding is adjusted by turning on and off switches (semiconductor switching elements) provided on the corresponding pair of upper and lower arms.

The inverter **30** includes an inverter control unit (not shown). The inverter control unit performs energization control by turning on and off each switch in the inverter **30** based on various items of detection information in the motor **20** and requests for power running and power generation. The inverter control unit thereby supplies electric power from the assembled battery **40** to the motor **20** via the inverter **30** to drive the motor **20** during power running. The inverter control unit causes the motor **20** to generate power based on the power from the drive wheels, converts the generated power and supplies it to the assembled battery **40** via the inverter **30** to charge the assembled battery **40**.

The assembled battery **40** is electrically connected to the motor **20** via the inverter **30**. The assembled battery **40**, with an inter-terminal voltage of, for example, one hundred V or higher, is formed of a plurality of battery modules **41** connected in series. Each battery module **41** is formed of a plurality of battery cells **42** connected in series. For example, a lithium-ion rechargeable battery or a nickel metal hydride rechargeable battery may be used as the battery cells **42**. Each battery cell **42** is a rechargeable battery including an electrolyte and a plurality of electrodes.

A positive-side terminal of an electric load such as an inverter **30** or the like is connected to a positive-side power source path L**1** that is connected to the positive-side power source terminal of the assembled battery **40**. Similarly, the negative-side terminal of the electrical load such as the inverter **30** or the like is connected to the negative-side power source path L**2** that is connected to the negative-side power source terminal of the assembled battery **40**. The positive-side power source path L**1** and the negative-side power source path L**2** are each provided with a relay switch referred to as a system main relay switch (SMR). The relay switch SMR is configured to switch between energization and de-energization.

The battery monitoring device **50** is a device that monitors a state of charge (SOC), a state of health (SOH), and the like of each battery cell **42**. In the first embodiment, the battery monitoring device **50** is provided for each battery cell **42**. The battery monitoring device **50** is connected to the ECU **60**, and outputs the state or the like of each battery cell **42**. The configuration of the battery monitoring device **50** will be described later.

The ECU **60** requests the inverter control unit for power running and power generation based on various information. The various information includes, for example, information about operations of the accelerator and the brake, the vehicle speed, and the state of the assembled battery **40**.

The battery monitoring device **50** will now be described in detail. As illustrated in FIG. **2**, in the first embodiment, the battery monitoring device **50** is provided for each battery cell **42**.

The battery monitoring device **50** includes an application specific integrated circuit (ASIC) unit **50***a*, a filter unit **55**, and a current modulation circuit **56**. The ASIC unit **50***a* includes a regulated power supply unit **51**, an input and output unit **52**, a microcomputer unit **53** as a calculation unit, and a communication unit **54**.

The regulated power supply unit **51** is connected to power lines of the battery cell **42**, and supplies electric power supplied from the battery cell **42** to the input and output unit **52**, the microcomputer unit **53**, and the communication unit **54**. The input and output unit **52**, the microcomputer unit **53**, and the communication unit **54** are driven based on this electric power.

The input and output unit **52** is connected to the battery cell **42** to be monitored. Specifically, the input and output unit **52** includes direct current (DC) voltage input terminals **57** for receiving (measuring) a DC voltage from the battery cell **42**. A filter unit **55** is provided between the battery cell **42** and the DC voltage input terminals **57**. That is, an RC filter **55***a* as a filter circuit and a Zener diode **55***b* as a protection element are provided between the positive-side terminal **57***a* and the negative-side terminal **57***b* of the DC voltage input terminals **57**. The RC filter **55***a*, the Zener diode **55***b*, and the like are connected in parallel to the battery cell **42**.

The input and output unit **52** includes response signal input terminals **58** for receiving a response signal (variations in voltage) reflecting the internal complex impedance information of the battery cell **42** between the terminals of the battery cell **42**. Therefore, the input and output unit **52** serves as a response signal input unit.

The input and output unit **52** is connected to the current modulation circuit **56** as a signal control unit, and includes an instruction signal output terminal **59***a* that outputs an instruction signal to the current modulation circuit **56** to instruct emission of a sinusoidal signal (AC signal) from the battery cell **42**. The input and output unit **52** further includes a feedback signal input terminal **59***b*. The feedback signal input terminal **59***b* receives, as a feedback signal, a current signal actually output (flowing) from the battery cell **42** via the current modulation circuit **56**.

The input and output unit **52** is connected to the microcomputer unit **53**, and is configured to output the DC voltage received at the DC voltage input terminal **57**, the response signal received at the response signal input terminal **58**, the feedback signal received at the feedback signal input terminal **59***b*, and the like, to the microcomputer unit **53**. The input and output unit **52**, which incorporates an AD converter, is configured to convert received analog signals into digital signals and output the digital signals to the microcomputer unit **53**.

The input and output unit **52** is configured to receive the instruction signal from the microcomputer unit **53** and output the instruction signal from the instruction signal output terminal **59***a* to the current modulation circuit **56**. The input and output unit **52**, which incorporates a DA converter to convert digital signals received from the microcomputer unit **53** into analog signals, is configured to output the instruction signal (analog signal) to the current modulation circuit **56**. The sinusoidal wave instructed by the instruction signal output to the current modulation circuit **56** is DC biased such that the sinusoidal wave signal does not become a negative current (current flowing back into the battery cell **42**).

The current modulation circuit **56** is a circuit that causes the battery cell **42** to be monitored, as a power source, to output a predefined AC signal (sinusoidal signal). Specifically, the current modulation circuit **56** includes a semiconductor switching element **56***a* (e.g., a MOSFET) as a switching unit and a resistor **56***b* connected in series with the semiconductor switching element **56***a*. A drain terminal of the semiconductor switching element **56***a* is connected to the positive terminal of the battery cell **42**, and a source terminal

of the semiconductor switching element **56***a* is connected to one end of the resistor **56***b*. The other end of the resistor **56***b* is connected to the negative electrode terminal of the battery cell **42**. The semiconductor switching element **56***a* is configured to adjust an amount of current between the drain terminal and the source terminal.

The positive terminal and the negative terminal of the battery cell **42** are respectively connected to the positive electrode and the negative electrode. Preferably, on each of the positive and negative sides of the battery cell **42**, it is desirable to connect the response signal input terminal **58** to a connectable point on the terminal of the battery cell **42**, closest to the electrode. Preferably, on each of the positive and negative sides of the battery cell **42**, it is also desirable to connect the DC voltage input terminal **57** to a connectable point on the terminal of the battery cell **42**, closest or next closest to the electrode. This allows the effect of the voltage drop due to the main current or the equalizing current to be minimized.

In the current modulation circuit **56**, a current detection amplifier **56***c* connected to both ends of the resistor **56***b* is provided as a current detection unit. The current detection amplifier **56***c* is configured to detect a signal (current signal) flowing through the resistor **56***b* and output the detected signal as the feedback signal to the feedback signal input terminal **59***b* of the input and output unit **52**.

In the current modulation circuit **56**, a feedback circuit **56***d* is provided. The feedback circuit **56***d* is configured to receive the instruction signal from the instruction signal output terminal **59***a* of the input and output unit **52** and receive the feedback signal from the current detection amplifier **56***c*. The feedback circuit **56***d* is configured to compare the instruction signal and the feedback signal, and output a result thereof to the gate terminal of the semiconductor switching element **56***a*.

Based on the signal from the feedback circuit **56***d*, the semiconductor switching element **56***a* adjusts the voltage applied between the gate and the source to thereby adjust the amount of current between the drain and the source so as to cause the battery cell **42** to output a sinusoidal signal (a predefined AC signal) instructed by the instruction signal. In cases where there is an error between the waveform instructed by the instruction signal and the waveform actually flowing through the resistor **56***b*, the semiconductor switching element **56***a* adjusts the amount of current based on the signal from the feedback circuit **56***d* to correct for the error. This can stabilize the sinusoidal signal flowing through the resistor **56***b*.

A method for calculating the complex impedance of the battery cell **42** will now be described. The battery monitoring device **50** performs a complex impedance calculation process illustrated in FIG. **3** in each predefined cycle.

In a complex impedance calculation process, the microcontroller **53** first sets a measurement frequency for the complex impedance (at step S**101**). The measurement frequency is set to a frequency within a predefined measurement range.

The microcomputer unit **53** determines the frequency of the sinusoidal signal (as a predefined AC signal) based on the measurement frequency, and outputs the instruction signal to the input and output unit **52** to instruct emission of the sinusoidal signal (at step S**102**).

Upon receipt of the instruction signal, the input and output unit **52** converts the instruction signal into an analog signal using the DA converter and outputs the analog signal to the current modulation circuit **56**. The current modulation circuit **56** causes the battery cell **42** as a power source to output a sinusoidal signal based on the instruction signal. Specifically, the semiconductor switching element **56***a* adjusts the amount of current based on the signal received via the feedback circuit **56***d* to cause the battery cell **42** to output the sinusoidal signal instructed by the instruction signal. This allows the sinusoidal wave signal to be output from the battery cell **42**.

Upon causing the battery cell **42** to output the sinusoidal signal, that is, upon applying a disturbance to the battery cell **42**, variations in voltage reflecting the internal complex impedance information of the battery cell **42** is generated between the terminals of the battery cell **42**. The input and output unit **52** receives the variations in voltage via the response signal input terminals **58** and outputs, after conversion by AD converter, the variations in voltage to the microcomputer unit **53** as a response signal.

After completion of step S**102**, the microcontroller unit **53** receives the response signal from the input and output unit **52** (at step S**103**). The microcontroller unit **53** also acquires the signal flowing through the resistor **56***b* of the current modulation circuit **56** (that is, the signal output from the battery cell **42**) as the current signal (at step S**104**). Specifically, the microcomputer unit **53** receives the feedback signal (detection signal) output from the current detection amplifier **56***c* as the current signal via the input and output unit **52**. Instead of the feedback signal, a value proportional to the instruction signal instructed to the current modulation circuit **56** may be used as the current signal.

Then, the microcomputer unit **53** calculates the complex impedance based on the response signal and the current signal (at step S**105**). That is, the microcomputer unit **53** calculates all or some of the real part, the imaginary part, the absolute value, and the phase of the complex impedance based on the amplitude of the response signal, the phase difference of the response signal from the current signal, and the like. The microcomputer unit **53** outputs a result of calculation to the ECU **60** via the communication unit **54** (at step S**106**). Thereafter, the calculation process ends.

This calculation process is repeatedly performed until complex impedances for a plurality of frequencies within the measurement range are calculated. The ECU **60** may generate a complex impedance plane plot (Cole-Cole plot) based on the results of calculation to acquire characteristics of the electrodes and electrolytes and the like, for example, the state of charge (SOC) and the state of health (SOH).

The entire Cole-Cole plot does not necessarily have to be generated, and a portion thereof may be focused on. For example, the complex impedance for a specific frequency may be measured at certain time intervals during driving to acquire changes in the SOC, the SOH, the battery temperature, and the like during driving based on variations with time in the complex impedance for the specific frequency. Alternatively, the complex impedance for the specific frequency may be measured at time intervals, such as every day, every week, or every year, to acquire variations with time in the SOH and the like based on variations with time in the complex impedance for the specific frequency.

The battery monitoring device **50** of the first embodiment provides the following advantages.

The current modulation circuit **56** causes the battery cell **42** to be monitored, as a power source, to output a sinusoidal signal (a predefined AC signal). This eliminates the need for an external power source for inputting the sinusoidal signal to the battery cell **42**, leading to a reduced number of parts, downsizing, and reduced costs.

Typically, the vehicle rechargeable battery is connected to peripheral circuits, such as protection elements and filter

circuits. Even when an AC signal is input to the rechargeable battery, a portion of the current may leak into these peripheral circuits. For example, even in the first embodiment, the RC filter **55***a* and the Zener diode **55***b* are connected to the battery cell **42**. Even when an AC signal is input to the battery cell **42**, a portion of the current may leak into these circuits. Thus, there has been an issue that, when calculating the complex impedance based on the response signal to the AC signal input to the battery cell **42**, errors in the response signal may occur due to the effect of the leakage current, leading to reduced accuracy of the complex impedance.

In the battery monitoring device **50** of the first embodiment described above, the battery cell **42** is used as a power source to output a sinusoidal signal, which enables implementation of a closed circuit formed of the current modulation circuit **56** and the battery cell **42**. Therefore, the leakage of the current from the battery cell **42** can be eliminated, and the errors in the response signal can be suppressed.

There may be errors between the signal actually flowing through the resistor **56***b* and the sinusoidal signal to be output from the battery cell **42**. This may cause errors in the response signal. Therefore, the feedback circuit **56***d* is provided to provide feedback based on a comparison between the feedback signal (detection signal) and the instruction signal when an instruction is provided to the semiconductor switching element **56***a*. This allows the instructed sinusoidal signal to be output stably and accurately from the battery cell **42**.

When the instruction signal provided to the current modulation circuit **56** instructs the waveform of the sinusoidal signal, the instruction signal is converted from a digital signal to an analog signal. This conversion may cause errors. Providing a filter circuit or the like between the input and output unit **52** and the current modulation circuit **56** can smooth the waveform of the instruction signal to suppress these errors, but providing such a filter circuit may lead to upsizing and increased costs.

In addition, since the vehicle battery cell **42** typically has a large capacity, the measurement range of measurement frequencies used to calculate the complex impedance tends to be wider, which is likely to lead to a larger filter circuit. Therefore, the feedback described above is performed to suppress errors in the waveform of the instruction signal caused by the signal conversion. This allows the filter circuit between the input and output unit **52** and the current modulation circuit **56** to be omitted.

The current modulation circuit **56** is configured to detect a signal flowing through the resistor **56***b* and output the detected signal as a feedback signal to the microcomputer unit **53** via the input and output unit **52**. The microcomputer unit **53** then calculates the complex impedance using the feedback signal as a current signal. With this configuration, even if an error (phase shift or the like) occurs between the signal actually flowing through the resistor **56***b* and the sinusoidal signal (the signal instructed by the microcomputer unit **53**) to be output, use of the feedback signal, that is, the signal actually flowing through the resistor **56***b*, can improve the calculation accuracy of the complex impedance.

The correction is made using the feedback signal as described above, which allows a filter circuit to be omitted between the input and output unit **52** and the current modulation circuit **56**, and thus allows the battery monitoring device **50** to be downsized.

The response signal input terminals **58** are connected to connectable points on the terminals of the battery cell **42**, closest to the respective electrodes of the battery cell **42**. This allows the effect of the impedance component of the terminals of the battery cell **42** to be suppressed, thereby further improving the calculation accuracy of the complex impedance. More specifically, as illustrated in FIGS. **4**A and **4**B, each terminal **42***a* of the battery cell **42** has an impedance component. Hence, on each of the positive and negative sides of the battery cell **42**, it is desirable to connect the response signal input terminal **58** to a connection point on the terminal **42***a*, closer to the electrode, as illustrated in FIG. **4**B rather than in FIG. **4**A. This can further improve the calculation accuracy of the complex impedance. As illustrated in FIG. **4**B, on each of the positive and negative sides of the battery cell **42**, the connection point on the terminal of the battery cell **42**, to which the response signal input terminal **58** is connected, is closer to the electrode than the connection point to which the current modulation circuit **56** is connected.

## Second Embodiment

The battery monitoring device **50** according to a second embodiment will now be described. The battery monitoring device **50** of the second embodiment implements so-called dual phase lock-in detection described in detail later. In the following, the components of the battery monitoring device **50** that are the same as or similar to those of the above embodiment are assigned the same reference numerals, and descriptions about these components will be omitted.

As illustrated in FIG. **5**, the ASIC unit **50***a* of the battery monitoring device **50** includes a differential amplifier **151** that measures the DC voltage between the terminals of the battery cells **42**. The differential amplifier **151** is connected between the DC voltage input terminals **57**, and is configured to measure and output the DC voltage.

In the ASIC unit **50***a* of the battery monitoring device **50**, a pre-amplifier **152** as an amplifier is provided to receive, via the response signal input terminals **58**, variations in the voltage of the battery cell **42** during the sinusoidal signal being output. The pre-amplifier **152** amplifies the variations in the voltage of the battery cell **42** received via the response signal input terminals **58** and outputs the amplified variations as a response signal. That is, since the amplitude of the response signal is a weak signal as compared to the voltage of the battery cell **42**, the pre-amplifier **152** is provided to improve the detection accuracy of the response signal. In the second embodiment, the pre-amplifier **152** is configured as having one stage, but it may be configured as having multiple stages.

As illustrated in FIG. **5**, a capacitor C**1** is provided between the positive terminal of the battery cell **42** and the positive response signal input terminal **58** (the positive terminal side of the pre-amplifier **152**) to cut off the DC component. This enables removal of the DC component (not related to the internal complex impedance information) from the variations in the voltage of the battery cell **42**, thereby improving the detection accuracy of the response signal.

In the ASIC unit **50***a*, a signal switcher **153** is provided to switch between the DC voltage output from the differential amplifier **151** and the response signal output from the pre-amplifier **152**. An AD converter **154** is connected to the signal switcher **153**, and is configured such that the switched signal (analog signal) is converted into a digital signal and output.

The AD converter **154** is connected to the signal processing unit **155** as a calculation unit in the second embodiment, and is configured to input the DC voltage to the signal processing unit **155**. The AD converter **154** is also connected

to a first multiplier **156** and a second multiplier **157**, and is configured to input the response signal to the first multiplier **156** and the second multiplier **157**.

An oscillation circuit **158**, which is described later, is connected to the first multiplier **156**, and is configured to input a first reference signal to the first multiplier **156**. The first multiplier **156** multiplies the first reference signal and the response signal, calculates a value proportional to the real part of the response signal, and outputs the value proportional to the real part of the response signal to the signal processing unit **155** via a low-pass filter **159**. In FIG. **5**, the real part of the response signal is denoted by Re|Vr|.

The second multiplier **157** is connected to the oscillation circuit **158** through a phase shift circuit **160**, and is configured to receive a second reference signal. The second reference signal is the first reference signal advanced in phase by 90 degrees (n/2). The phase shift circuit **160** advances the phase of the sinusoidal signal (the first reference signal) received from the oscillation circuit **158** and outputs it as the second reference signal.

The second multiplier **157** multiplies the second reference signal and the response signal to calculate a value proportional to the imaginary part of the response signal, and outputs the value proportional to the imaginary part of the response signal to the signal processing unit **155** via a low-pass filter **161**. In FIG. **5**, the imaginary part of the response signal is denoted by Im|Vr|.

The oscillation circuit **158** is a circuit that outputs the sinusoidal signal set therein and serves as a waveform instruction unit. As described above, the oscillation circuit **158** outputs the sinusoidal wave signal as the first reference signal to the first multiplier **156** and the phase shift circuit **160**. The oscillation circuit **158** is connected to the instruction signal output terminal **59***a* via the DA converter **162**, and outputs the sinusoidal wave signal as the instruction signal.

The feedback signal input terminal **59***b* is connected to the signal processing unit **155** via the AD converter **163**. The signal processing unit **155** receives the feedback signal (detection signal) from the feedback signal input terminal **59***b* via the AD converter **163**.

The signal processing unit **155** receives the value proportional to the real part of the response signal and the value proportional to the imaginary part of the response signal, and calculates the real part and the imaginary part of the complex impedance based on those values. To this end, the signal processing unit **155** calculates (corrects) the real and imaginary parts of the complex impedance using the received feedback signal and taking into account the amplitude and the phase shift from the reference signal, of the signal actually flowing.

The signal processing unit **155** calculates the absolute value and the phase of the complex impedance. More specifically, since the real and imaginary parts of the response signal are acquired by the dual phase lock-in detection, the response signal can be expressed as $|Vr|e^{j\theta v}$ in the polar coordinate representation of the complex plane, where θv is the phase of the response signal and "j" is the imaginary unit that satisfies $j^2=-1$. Similarly, the current can be expressed as $|I|e^{j\theta i}$. In the polar coordinate representation, the complex impedance $|Z|e^{j\theta z}$ can be expressed as equation (1) derived from V=ZI.

$$|Z|e^{j\theta z} = \frac{|Vr|e^{j\theta v}}{|I|e^{j\theta i}} \quad (1)$$

Therefore, the absolute value of the complex impedance can be acquired from |Z|=|Vr|/|I|, and the phase can be acquired from θv−θi. Then, the signal processing unit **155** outputs this calculation result to the ECU **60** via the communication unit **54**. In FIG. **5**, the absolute value of the complex impedance is denoted by |Z|, and its phase is denoted by arg(Z).

A complex impedance calculation process in the second embodiment will now be described with reference to FIG. **6**. The complex impedance calculation process is performed every predefined cycle by the battery monitoring device **50**.

In the complex impedance calculation process, the oscillation circuit **158** first sets a measurement frequency for the complex impedance (at step S**201**). The measurement frequency is set to a frequency within a predefined measurement range. In the second embodiment, the measurement frequency is determined, for example, by the signal processing unit **155**.

The signal switcher **153** makes a switch such that the response signal from the pre-amplifier **152** is output (at step S**202**). The switching is instructed, for example, by the signal processing unit **155**.

The oscillation circuit **158** determines a frequency of the sinusoidal signal (predefined AC signal) based on the measurement frequency, and outputs an instruction signal that instructs to the current modulation circuit **56** emission of the sinusoidal signal, from the instruction signal output terminal **59***a* via the DA converter **162** (at step S**203**). The instruction for outputting the instruction signal is provided, for example, by the signal processing section **155**. In conversion into an analog signal by the DA converter **162**, an appropriate offset value (DC bias) is set taking into account the voltage of the battery cell **42**. The offset value (DC bias) is set, for example, by the signal processing unit **155**. It is desirable that the offset value (DC bias) is set based on the DC voltage of the battery cell **42**. The DC voltage of the battery cell **42** may be measured by the differential amplifier **151**.

The current modulation circuit **56** causes the battery cell **42** as a power source to output a sinusoidal signal based on the instruction signal (at step S**204**). Thus, the sinusoidal wave signal is output from the battery cell **42**.

Upon causing the battery cell **42** to output the sinusoidal signal, variations in the voltage reflecting the internal complex impedance information of the battery cell **42** occur between the terminals of the battery cell **42**. The pre-amplifier **152** receives the variations in the voltage of the of the battery cell **42** via the response signal input terminal **58** and outputs the variations in the voltage of the battery cell **42** as a response signal (at step S**205**).

When the variations in voltage are input to the response signal input terminals **58**, the DC component of the variations in voltage is cut off by the capacitor C**1**, and only characteristic portions of the variations in voltage are extracted. The pre-amplifier **152** amplifies the weak variations in voltage with the DC component cut off and outputs them as a response signal. Then, the AD converter **154** converts the response signal received via the signal switcher **153** into a digital signal and outputs it. Preferably, the magnitude of the DC component cut off by the capacitor C**1** is adjusted based on the DC voltage of the battery cell **42**. Also preferably, to what degree the variations in voltage are amplified is adjusted based on the DC voltage of the battery cell **42**.

The first multiplier **156** uses the sinusoidal signal received from the oscillation circuit **158** as the first reference signal and multiplies the first reference signal and the response

signal received from the AD converter **154** to calculate a value proportional to the real part of the response signal (at step S**206**). Similarly, the second multiplier **157** multiplies the second reference signal received from the phase shift circuit **160** and the response signal to calculate a value proportional to the imaginary part of the response signal.

These values are input to the signal processing unit **155** through the low-pass filter **159** and the low-pass filter **161**. Signals other than DC components are attenuated and removed during passing through the low-pass filter **159** and the low-pass filter **161**.

The signal processing unit **155** receives a feedback signal (detection signal) from the feedback signal input terminal **59***b* (at step S**207**). When the feedback signal is input to the signal processing unit **155**, it is converted into a digital signal by the AD converter **163**.

The signal processing unit **155** calculates all or some of the real part, the imaginary part, the absolute value, and the phase of the complex impedance based on the feedback signal and the signals (values proportional to the real part and the imaginary part of the response signal) received from the low-pass filters **159** and **161** (at step S**208**). The feedback signal is used to correct for any deviation in amplitude or phase between the current actually flowing from the battery cell **42** (i.e., the feedback signal) and the value proportional to the reference signal.

Thereafter, the signal processing unit **155** outputs the result of calculation to the ECU **60** via the communication unit **54** (at step S**209**). Then, the complex impedance calculation process ends.

This calculation process is repeatedly performed until complex impedances for a plurality of frequencies within the measurement range are calculated. The ECU **60** may generate a complex impedance plane plot (Cole-Cole plot) based on the results of calculation to acquire characteristics of the electrodes and electrolytes and the like, for example, the state of charge (SOC) and the state of health (SOH).

The entire Cole-Cole plot does not necessarily have to be generated, and a portion thereof may be focused on. For example, the complex impedance for a specific frequency may be measured at certain time intervals during driving to acquire changes in the SOC, the SOH, the battery temperature, and the like during driving based on variations with time in the complex impedance for the specific frequency. Alternatively, the complex impedance for the specific frequency may be measured at time intervals, such as every day, every month, or every year, to acquire variations with time in the SOH and the like based on variations with time in the complex impedance for the specific frequency.

The battery monitoring device **50** of the second embodiment provides the following advantages.

The signal processing unit **155** calculates the value proportional to the real part of the response signal based on the value acquired by multiplying the response signal received from the response signal input terminal **58** and the first reference signal. In addition, the signal processing unit **155** calculates the value proportional to the imaginary part of the response signal based on the value acquired by multiplying the response signal and the second reference signal, where the second reference signal is the first reference signal shifted in phase. Then, the complex impedance is calculated based on these values. In this way, performing so-called lock-in detection allows only the frequency component of the same frequency as the frequency of the sinusoidal signal instructed by the oscillation circuit **158** to be extracted from the response signal. This leads to increased resistance to white noise and pink noise. Therefore, the complex impedance can be calculated with high accuracy. In particular, even in a noisy environment, such as in a vehicle, the complex impedance can be suitably calculated. In addition, such increased resistance to noise allows the current (sinusoidal signal) output from the battery cell **42** to be decreased. Therefore, power consumption and temperature rise of the battery cell **42** and the semiconductor switching element **56***a* can be suppressed.

The signal processing unit **155** receives from the current modulation circuit **56** the feedback signal (detection signal) that is a current signal actually flowing from the battery cell **42**, and using the feedback signal, corrects for the deviations in amplitude and phase from the value proportional to the reference signal. This can improve the accuracy of the calculation of the complex impedance.

In addition, even if errors occur during conversion of the instruction signal into an analog signal, correcting for the deviations in amplitude and phase using the feedback signal enables suppression of such errors. Therefore, there is no need for providing a filter circuit or the like between the current modulation circuit **56** and the DA converter **162**, which enables downsizing.

## Third Embodiment

The battery monitoring device **50** according to a third embodiment will now be described. The battery monitoring device **50** of the third embodiment performs a fast Fourier transform (FFT) in signal analysis, which will be described in detail later. In the following, the components of the battery monitoring device **50** that are the same as or similar to those of each of the above embodiments are assigned the same reference numerals, and descriptions about these components will be omitted.

As illustrated in FIG. **7**, the ASIC unit **50***a* of the battery monitoring device **50** includes a signal processing unit **201** as a calculation unit that performs a fast Fourier transform. The signal processing unit **201** is configured to receive a measured value of the DC voltage of the battery cell **42** via the AD converter **154**. The signal processing unit **201** is also configured to receive the response signal via the AD converter **154**. The signal processing unit **201** is also configured to receive the feedback signal via the AD converter **163**. The signal processing unit **201** is connected to the oscillation circuit **158**, and is configured to set the frequency of the sinusoidal signal.

The signal processing unit **201** is configured to performs a fast Fourier transform on each of the received response signal (voltage signal) and the received feedback signal (current signal). The signal processing unit **201** calculates the real part, the imaginary part, the absolute value, and the phase of the complex impedance based on the transformed values. Then, the signal processing unit **201** outputs a result of calculation to the ECU **60** via the communication unit **54**.

The complex impedance calculation process in the third embodiment will now be described with reference to FIG. **8**. The complex impedance calculation process is performed every predefined cycle by the battery monitoring device **50**. In the complex impedance calculation process of the third embodiment, the process steps S**301** to S**305** are the same as the process steps S**201** to S**205** in the complex impedance calculation process of the second embodiment. The process steps of setting the measurement frequency, instructing the switch, instructing emission of the instruction signal, setting the offset value, and the like are performed, for example, by the signal processing unit **201**.

The signal processing unit **201** performs a fast Fourier transform on the response signal received from the AD converter **154** (at step S**306**). This allows amplitude information of the response signal with respect to the measurement frequency to be acquired.

The signal processing unit **201** receives the feedback signal from the feedback signal input terminal **59***b* (at step S**307**). The feedback signal is converted into a digital signal by the AD converter **163** when it is input to the signal processing unit **155**.

The signal processing unit **201** performs a fast Fourier transform on the feedback signal (at step S**308**). This allows amplitude information of the feedback signal for the measurement frequency to be acquired.

The signal processing unit **201** calculates all or some of the real part, the imaginary part, the absolute value, and the phase of the complex impedance based on the amplitude information of the response signal for the measurement frequency acquired at step S**306** and the amplitude information of the feedback signal for the measurement frequency acquired at step S**308** (at step S**309**). Thereafter, the signal processing unit **201** outputs a result of calculation to the ECU **60** via the communication unit **54** (at step S**310**). Then, the calculation process ends.

This calculation process is repeatedly performed until complex impedances for a plurality of frequencies within the measurement range are calculated. The ECU **60** may generate a complex impedance plane plot (Cole-Cole plot) based on the results of calculation to acquire characteristics of the electrodes and electrolytes and the like, for example, the state of charge (SOC) and the state of health (SOH).

The entire Cole-Cole plot does not necessarily have to be generated, and a portion thereof may be focused on. For example, the complex impedance for a specific frequency may be measured at certain time intervals during driving to acquire changes in the SOC, the SOH, the battery temperature, and the like during driving based on variations with time in the complex impedance for the specific frequency. Alternatively, the complex impedance for the specific frequency may be measured at time intervals, such as every day, every month, or every year, to acquire variations with time in the SOH and the like based on variations with time in the complex impedance for the specific frequency.

The battery monitoring device **50** of the third embodiment provides the following advantages.

Each of the response signal and the feedback signal is Fourier transformed to acquire the amplitude and phase information for the measurement frequency and the amplitude and phase information for the harmonics of the measurement frequency. Since the amplitude and phase information of the voltage and the current can be acquired for the measurement frequency and its harmonics, it is possible to calculate the complex impedance for multiple frequencies at once.

The signal processing unit **201** receives from the current modulation circuit **56** the feedback signal (detection signal) that is a current signal actually flowing from the battery cell **42**, and performs a Fourier transform on the feedback signal. This allows the amplitude and phase deviations to be corrected. Therefore, the calculation accuracy of the complex impedance can be improved.

## Other Embodiments

(O**1**) In each of the above embodiments, the battery monitoring device **50** is provided for each battery cell **42**, but the battery monitoring device **50** may be provided for a plurality of battery cells **42** (e.g., for each battery module **41** or for each assembled battery **40**). In such an embodiment, some of the functions of the battery monitoring device **50** may be shared.

For example, as illustrated in FIG. **9**, the stabilized power supply unit **301**, the communication unit **54**, and the microcontroller unit **53** may be shared. In such an embodiment, the potential on the negative electrode may be different for each battery cell **42**. Thus, the reference potential of each electrical signal used in transmitting information related to each battery cell **42** may be different. Therefore, it is necessary to provide a function for inputting each electrical signal to the microcomputer unit **53** for calculation, taking into account the differences in reference potential. As means for transmitting signals between different reference potentials, there are methods using capacitors, transformers, radio waves, and light.

For example, as illustrated in FIG. **10**, the stabilized power supply unit **301**, the communication unit **54**, the differential amplifier **151**, the pre-amplifier **152**, the signal switcher **153**, the AD converters **154**, **163**, the signal processing unit **155**, the first multiplier **156**, the second multiplier **157**, the low pass filters **159**, **161**, the oscillation circuit **158**, the phase shift circuit **160**, the DA converter **162**, the feedback circuit **56***d*, and the current detection amplifier **56***c* may be shared.

In such an embodiment, multiplexing devices, such as multiplexers **302** to **304**, may be used to switch various signals, such as the DC voltage, the response signal, and the instruction signal.

Similarly, for example, as illustrated in FIG. **11**, the stabilized power supply **301**, the communication unit **54**, the differential amplifier **151**, the pre-amplifier **152**, the signal switcher **153**, the AD converters **154**, **163**, the signal processing unit **201**, the oscillation circuit **158**, the DA converter **162**, the feedback circuit **56***d*, and the current detection amplifier **56***c* may be shared.

In such an embodiment, multiplexing devices, such as multiplexers **302** to **304**, may be used to switch various signals, such as the DC voltage, the response signal, and the instruction signal.

Either one part in which the high potential side and the low potential side of the plurality of battery cells **42** connected in series are used as the positive and negative terminals, respectively, or another part, in which the high potential side and the low potential side of one battery cell **42** are used as the positive and negative terminals, respectively, may be shared. For example, as illustrated in FIG. **12**, the communication unit **54**, the AD converters **154**, **163**, the signal processing unit **155**, **201**, the oscillation circuit **158**, the phase shift circuit **160**, and the DA converter **162** may be shared. In FIG. **12**, the first multiplier **156**, the second multiplier **157**, and the low-pass filters **159**, **161** are omitted, but in an embodiment where the signal processing unit **155** that performs lock-in detection is employed, they may also be shared.

The shared part is supplied with electric power from the first power supply **401**, and the first power supply **401** is supplied with electric power from the plurality of battery cells **42**. Each non-shared part is supplied with electric power from the second power supply **402**, and power is supplied to the second power supply **402** from a corresponding one of the plurality of battery cells **42**. The output voltage of the first power supply **401** and the output voltage of the second power supply **402** are different.

In such an embodiment, multiplexing devices, such as multiplexers **302** to **304**, may be used to switch various signals, such as the DC voltage, the response signal, and the instruction signal.

In the battery monitoring device **50** illustrated in each of FIGS. **9** to **11**, a plurality of power sources may be provided in the same manner as in the battery monitoring device **50** illustrated in FIG. **12**.

(O**2**) In each of the above embodiments, the battery monitoring device **50** may perform an equalization process to equalize the state of charge and the voltage of each battery cell **42**. The equalization process is a process of discharging some of the battery cells **42** having a higher state of charge than other battery cells **42** so as to equalize the state of charge of each battery cell **42**. With this configuration, the state of charge of each battery cell **42** can be equalized, and overcharging of some of the battery cells **42** can be inhibited. When the battery monitoring device **50** performs the equalization process, the battery cells **42** may be discharged by using the current modulation circuit **56**, where the battery monitoring device **50** serves as a discharge control unit.

Specifically, in the first embodiment, upon receiving a discharge instruction from the ECU **60** or the like based on the state of charge or the voltage of each battery cell **42** or in response to the state of charge or the voltage of each battery cell **42** exceeding a predefined value, the microcomputer unit **53** outputs the instruction signal to the current modulation circuit **56** to cause the battery cell **42** to output a periodic function such as a sinusoidal wave signal or a rectangular wave, or a direct current signal. The microcomputer unit **53** continues outputting the instruction signal until the discharge instruction ends or until the state of charge or the voltage of the battery cell **42** becomes less than the predefined value. In this way, the equalization process is carried out. Similarly in the second or third embodiment, the signal processing unit **155**, **201** may perform the equalization process. Also, in the battery monitoring device **50** illustrated in FIGS. **9** to **12**, the equalization processing may be similarly performed.

Then, when discharging from the battery cell **42** for the equalization process, the sinusoidal signal may be output and the complex impedance may thereby be calculated. This allows the power consumption to be suppressed. The current to be output for the equalization process is typically considered to be a weak current in order to suppress power consumption and to reduce the size of the device. Therefore, it is preferable to have the equalization process performed by the battery monitoring device **50** which can accurately calculate the complex impedance by lock-in detection even with a weak current as in the second embodiment.

(O**3**) In each of the above embodiments, the filter unit **55** may not be formed solely of an element. For example, it may be configured by wiring, a connector contact part, a pattern wiring of a printed circuit board or between solid patterns, or by a mixture of these configurations and elements.

(O**4**) In each of the above embodiments, a filter circuit may be provided between the current modulation circuit **56** and the input and output unit **52** (or the DA converter **162**). This can suppress errors that may occur during conversion of the instruction signal to an analog signal.

(O**5**) In each of the above embodiments, all or some of the differential amplifier **151**, the pre-amplifier **152**, the signal switcher **153**, the AD converters **154**, **163**, the signal processing unit **155**, the first multiplier **156**, the second multiplier **157**, the low pass filters **159**, **161**, the oscillation circuit **158**, the phase shift circuit **160**, the DA converter **162**, the feedback circuit **56***d*, and the current detection amplifier **56***c* may be implemented by software.

(O**6**) In each of the second and third embodiments above, there may be no capacitor C**1**.

(O**7**) In each of the above embodiments, there may be no feedback circuit **56***d*. The current flowing through the resistor **56***b* may not be detected by the current detection amplifier **56***c*. The microcomputer unit **53** and the signal processing units **155**, **201** may not need to receive the feedback signal.

(O**8**) In each of the above embodiments, the DC voltage is detected. In alternative embodiment, the DC voltage does not have to be detected.

(O**9**) In the above second or third embodiment, the signal switcher **153** may not be provided.

(O**10**) In the above second or third embodiment, the feedback signal may also be switched by the signal switcher **153**. The AD converters **154** and **163** may thereby be shared.

(O**11**) The battery monitoring device **50** of each of the above embodiments may be employed in a hybrid electric vehicle (HEV), an electric vehicle (EV), a plug-in hybrid vehicle (PHV), an auxiliary battery, an electric airplane, an electric motorcycle, or an electric ship as a vehicle.

(O**12**) In each of the above embodiments, the battery cells **42** may be connected in parallel.

(O**13**) In the above second or third embodiment, a filter circuit may be provided before or after the pre-amplifier **152** or immediately before the AD converter **154** in order to prevent aliasing during AD conversion.

(O**14**) In each of the above embodiments, the state may be monitored for each battery module **41**. In such an embodiment that the communication unit **54** is provided for each battery module **41**, communication from each communication unit **54** to the ECU **60** may be isolated communication with a different voltage potential reference. For example, the isolated communication may be performed using an isolation transformer or a capacitor.

(O**15**) In each of the above embodiments, the feedback signal may be a lock-in detection. Specifically, as illustrated in FIG. **13**, the complex impedance calculation process is performed by the battery monitoring device **50** every predefined cycle.

In the complex impedance calculation process, the oscillation circuit **158** first sets a measurement frequency for the complex impedance (at step S**401**). The measurement frequency is set to a frequency within a predefined measurement range. In another example, the measurement frequency is determined, for example, by the signal processing unit **155**.

The oscillation circuit **158** determines the frequency of the sinusoidal signal (predefined AC signal) based on the measurement frequency, and outputs the instruction signal from the instruction signal output terminal **59***a* to the current modulation circuit **56** via the DA converter **162** to instruct emission of the sinusoidal signal (at step S**402**). Based on the instruction signal, the current modulation circuit **56** causes the battery cell **42** to output the sinusoidal signal as a power source. Thus, the sinusoidal wave signal is output from the battery cell **42**.

Then, the signal processing unit **155** measures the feedback signal by means of dual phase lock-in detection (at step S**403**). Specifically, the signal processing unit **155** multiplies the sinusoidal signal (reference signal) instructed by the oscillation circuit **158** and the received feedback signal. The signal processing unit **155** multiplies the sinusoidal signal instructed by the oscillation circuit **158** shifted in phase by 90 degrees and the received feedback signal. The signal

processing unit **155** calculates the amplitude and the phase of the feedback signal from these multiplication results.

The signal processing unit **155** then determines whether a difference between the calculated value of amplitude and a corrected value of amplitude is within a reference value of amplitude (at step S**404**). The corrected value of amplitude refers to an amplitude of the sinusoidal signal that is expected to be output.

If the answer is NO, the signal processing unit **155** determines whether the number of measurements (the number of measurements of the feedback signal) by the step S**403** is equal to or greater than a predefined number of times (at step S**405**). If the answer is NO, the signal processing unit **155** increments the number of measurements by one and returns to step S**403**.

If the answer is YES at step S**405**, the signal processing unit **155** calculates an average of the measured amplitudes of the feedback signals and rewrites the corrected value of amplitude to the average of the measured amplitudes (step S**406**). Thereafter, the number of measurements is cleared.

If the answer is YES at step S**404**, or after completion of step S**406**, the signal processing unit **155** determines whether a difference between the value of phase calculated at step S**403** and the corrected value of phase is within a reference value of phase (at step S**407**). The corrected value of phase refers to a phase of the sinusoidal signal that is expected to be output.

If the answer is NO at step S**407**, the signal processing unit **155** determines whether the number of measurements (the number of measurements of the feedback signal) by step S**403** is equal to or greater than a predefined number of times (at step S**408**). If the answer is NO, the signal processing unit **155** increments the number of measurements by one and returns to step S**403**.

If the answer is YES at step S**408**, the signal processing unit **155** calculates an average of the measured phases of the feedback signals and rewrites the corrected value of phase to the average of the measured phases (step S**409**). Thereafter, the number of measurements is cleared.

Subsequently, the signal processing unit **155** measures the response signal by dual phase lock-in detection (at step S**410**). This process step is the same as steps S**202**, S**205**, S**206** of the second embodiment, so the description is omitted.

The signal processing unit **155** calculates all or some of the real part, the imaginary part, the absolute value, and the phase of the complex impedance based on the feedback signal and the signals (values proportional to the real part and the imaginary part) received from the low-pass filters **159** and **161** (at step S**411**). The feedback signal is determined by the corrected value of amplitude and the corrected value of phase, and is used to correct for the amplitude or phase deviation between the current actually flowing from the battery cell **42** (i.e., the feedback signal) and the value proportional to the reference signal.

Thereafter, the signal processing unit **155** outputs the result of calculation to the ECU **60** via the communication unit **54** (at step S**412**). Then, the complex impedance calculation process ends.

As described above, since the feedback signal is measured by the dual phase lock-in detection, the current signal actually output from the battery cell **42** can be measured accurately even in a noisy environment. In addition, since this feedback signal is used for correction when calculating the complex impedance, the calculation accuracy of the complex impedance can be improved.

(O**16**) In each of the above embodiments, the current signal to be output from the battery cell **42** is not limited to a sinusoidal wave signal. For example, as long as it is an AC signal, it can be a square wave, a triangular wave, or the like.

(O**17**) In each of the above embodiments, the ECU **60** may include a plurality of ECUs. For example, a plurality of ECUs may be provided for respective functions, or a plurality of ECUs may be provided for respective components to be controlled. For example, the plurality of ECUs may include a battery ECU and an inverter control ECU.

(O**18**) In each of the above embodiments, when lock-in detection is performed, the sinusoidal signal instructed by the oscillation circuit **158** is used as the reference signal (first reference signal). In an alternative embodiment, the detection signal (feedback signal) may be used as the reference signal. When dual phase lock-in detection is performed, the detection signal (feedback signal) shifted in phase may be the second reference signal.

(O**19**) In each of the above embodiments, the battery cell **42** (the battery module **41**, the assembled battery **40**) may be used as a power source for peripheral circuits while outputting the sinusoidal wave signal based on the instruction (while the response signal is being output). Conversely, the battery cell **42** (the battery module **41**, the assembled battery **40**) may not be configured to be used as a power source for peripheral circuits when outputting the sinusoidal wave signal based on the instruction (while the response signal is being output).

While the disclosure has been described in accordance with the embodiments, it is understood that the disclosure is not limited to such embodiments or structures. The disclosure also encompasses various modifications and variations within the scope of equivalence. Furthermore, various combinations and modes, as well as other combinations and modes including only one element, more or less, thereof, are also within the scope and idea of the disclosure.

What is claimed is:

**1**. A battery monitoring device for monitoring a state of a rechargeable battery that includes an electrolyte and a plurality of electrodes, comprising:

a signal control unit configured to instruct emission of a predefined AC signal;

a response signal input unit configured to receive a response signal of the rechargeable battery to the AC signal;

a calculation unit configured to calculate a complex impedance of the rechargeable battery based on the response signal; and

a power supply unit configured to receive a power supply voltage from the rechargeable battery and supplies the power supply voltage to at least the calculation unit; and

a waveform instruction unit configured to output an instruction signal to indicate a waveform of the AC signal to the signal control unit,

wherein a first electrical path connecting the rechargeable battery to the power supply unit and a second electrical path connecting the rechargeable battery to the signal control unit are provided independent of each other,

the signal control unit is configured to cause the rechargeable battery to be monitored, as a power source, to output the predefined AC signal,

the signal control unit includes a switching unit configured to adjust an amount of current based on an

instruction, a resistor connected in series with the switching unit, a current detection unit configured to detect a current flowing through the resistor, and an instruction unit configured to provide the instruction to the switching unit, the instruction unit being configured to provide the instruction to the switching unit so as to make a correction for errors in a detection signal detected by the current detection unit based on a comparison between the detection signal and the instruction signal,

the calculation unit is configured to perform dual phase lock-in detection to determine an amplitude and a phase of the detection signal based on a value calculated by multiplying the instruction signal indicated by the waveform instruction unit and the detection signal from the current detection unit, and a value calculated by multiplying a signal acquired by shifting a phase of the instruction signal by a predefined angle and the detection signal, and

the calculation unit is configured to calculate the complex impedance based on the response signal and a detection signal detected by the dual phase lock-in detection.

**2**. The battery monitoring device according to claim **1**, wherein

a third electrical path connecting the rechargeable battery to the response signal input unit, through which the response signal flows, is provided independent of the first electrical path connecting the rechargeable battery to the power supply unit and the second electrical path connecting the rechargeable battery to the signal control unit.

**3**. The battery monitoring device according to claim **1**, wherein

the response signal input unit is connected to connectable points on terminals of the rechargeable battery, closest to respective electrodes of the rechargeable battery.

**4**. The battery monitoring device according to claim **1**, wherein

the rechargeable battery comprises a plurality of rechargeable battery cells,

the battery monitoring device further comprises a discharge control unit configured to acquire the state of each of the plurality of rechargeable battery cells and discharge the rechargeable battery cells such that the states of the respective rechargeable battery cells are equalized, the discharge control unit being configured to instruct to the signal control unit discharge from the rechargeable battery cells.

**5**. The battery monitoring device according to claim **4**, wherein

the calculation unit is configured to calculate the complex impedance while the discharge control unit is instructing the discharge.

**6**. The battery monitoring device according to claim **1**,

wherein the calculation unit is configured to calculate a real part of the response signal received from the response signal input unit based on a value acquired by multiplying the response signal and a first reference signal which is the AC signal instructed by the waveform instruction unit, and calculate an imaginary part of the response signal received from the response signal input unit based on a value acquired by multiplying the response signal and a second reference signal which is the AC signal instructed by the waveform instruction unit, shifted in phase.

**7**. The battery monitoring device according to claim **1**, wherein

the calculation unit is configured to perform a Fourier transform on each of the response signal and the AC signal to calculate the complex impedance.

**8**. The battery monitoring device according to claim **1**, wherein

the calculation unit is configured to perform a Fourier transform on each of the response signal and the detection signal detected by the current detection unit to calculate the complex impedance.

**9**. The battery monitoring device according to claim **1**, wherein

the response signal input unit is configured to receive variations in voltage of the rechargeable battery through a capacitor and has one or more stages of amplifiers, and amplify the received variations in voltage of the rechargeable battery via the amplifiers and outputs a result of amplification as the response signal.

**10**. The battery monitoring device according to claim **1**, wherein

at least one of a filter circuit and a protection element is connected to the rechargeable battery.

**11**. The battery monitoring device according to claim **1**, wherein

the rechargeable battery comprises a plurality of rechargeable battery cells, and

the state of each of the plurality of rechargeable battery cells is monitored using the calculation unit.

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