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(54) **VOLTAGE DETECTION DEVICE AND VOLTAGE DETECTION METHOD**

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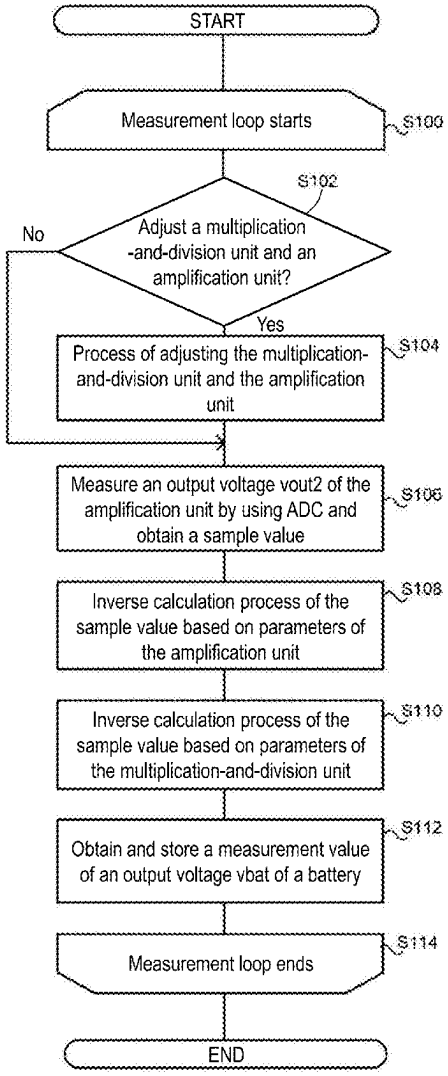
(57) **ABSTRACT**

A voltage detection device, measuring a voltage of a battery by using an analog-to-digital converter (ADC). The voltage detection device includes: a level shift unit, shifting a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC; an amplification unit, amplifying the voltage signal in which the voltage level is shifted by the level shift unit; the ADC, measuring the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and a derivation unit, deriving a voltage value of a voltage of the battery based on the sample signal output from the ADC.



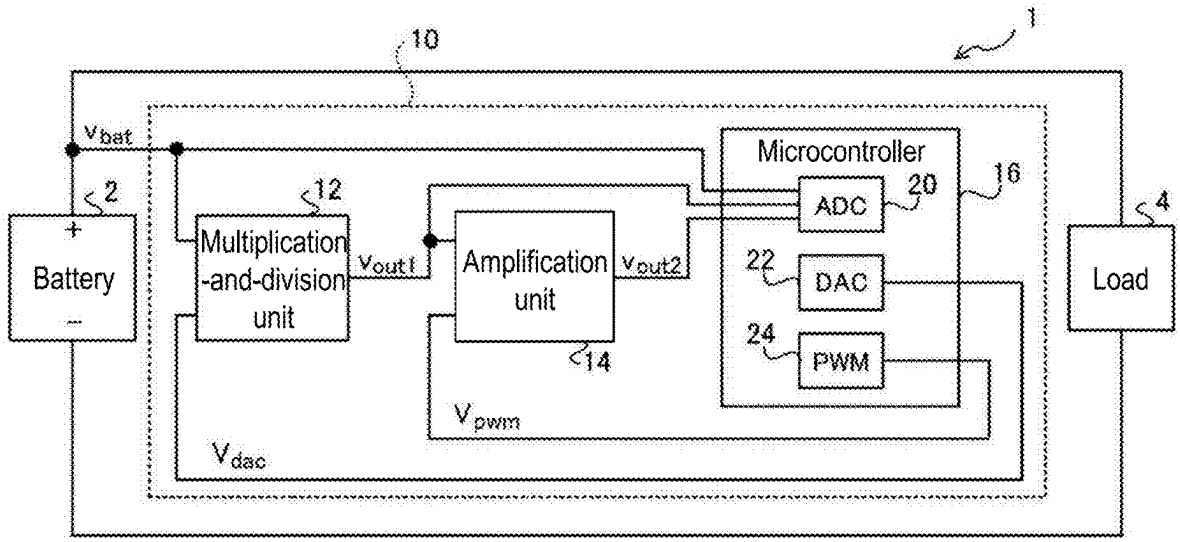

10
1
V_{bat}
2
+
Battery
–
12
Multiplication
-and-division
unit
V_{out1}
Amplification
unit
V_{out2}
14
Microcontroller
16
ADC
20
22
DAC
24
PWM
4
Load
V_{pwm}
V_{dac}

FIG. 1

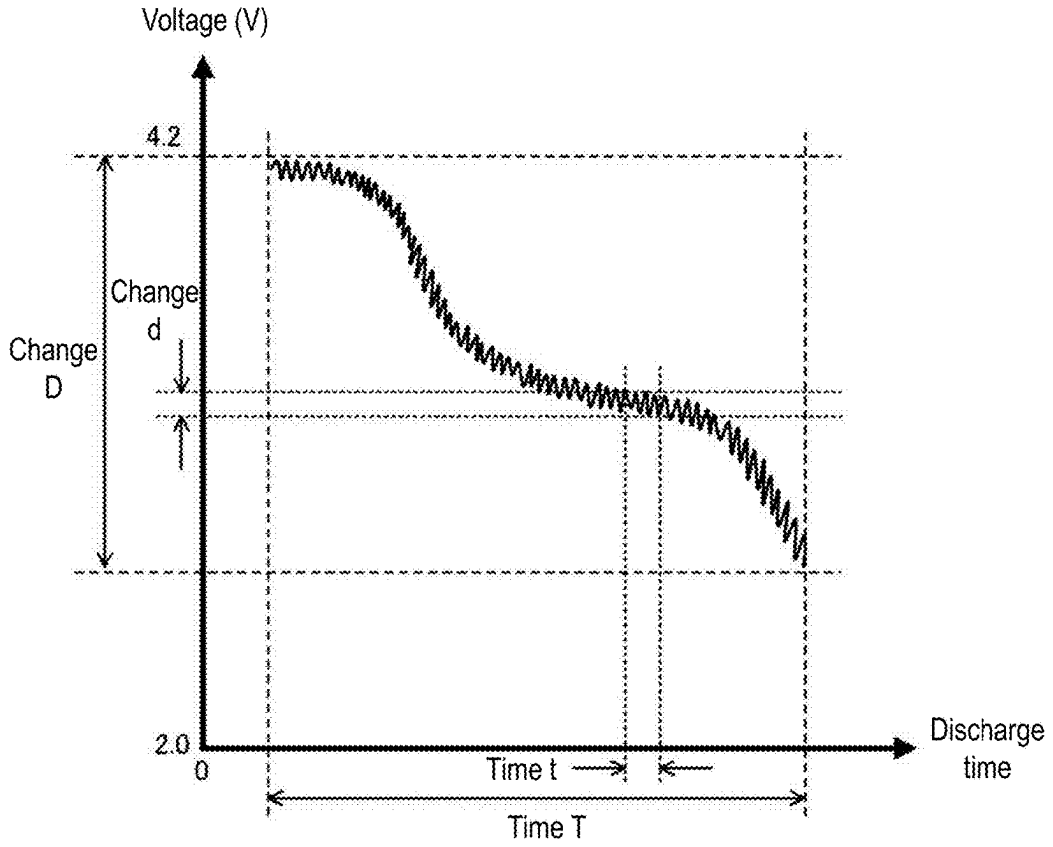

Voltage (V)
4.2
Change
d
Change
D
2.0
0
Time t
Time T
Discharge
time

FIG. 2

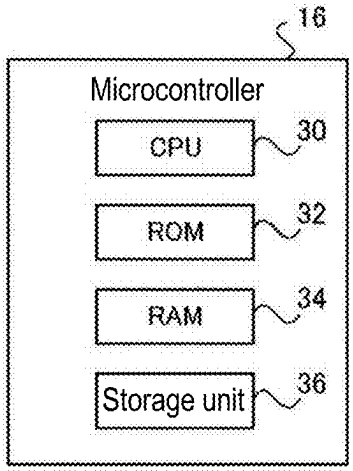

16
Microcontroller
CPU
30
ROM
32
RAM
34
Storage unit
36

FIG. 3

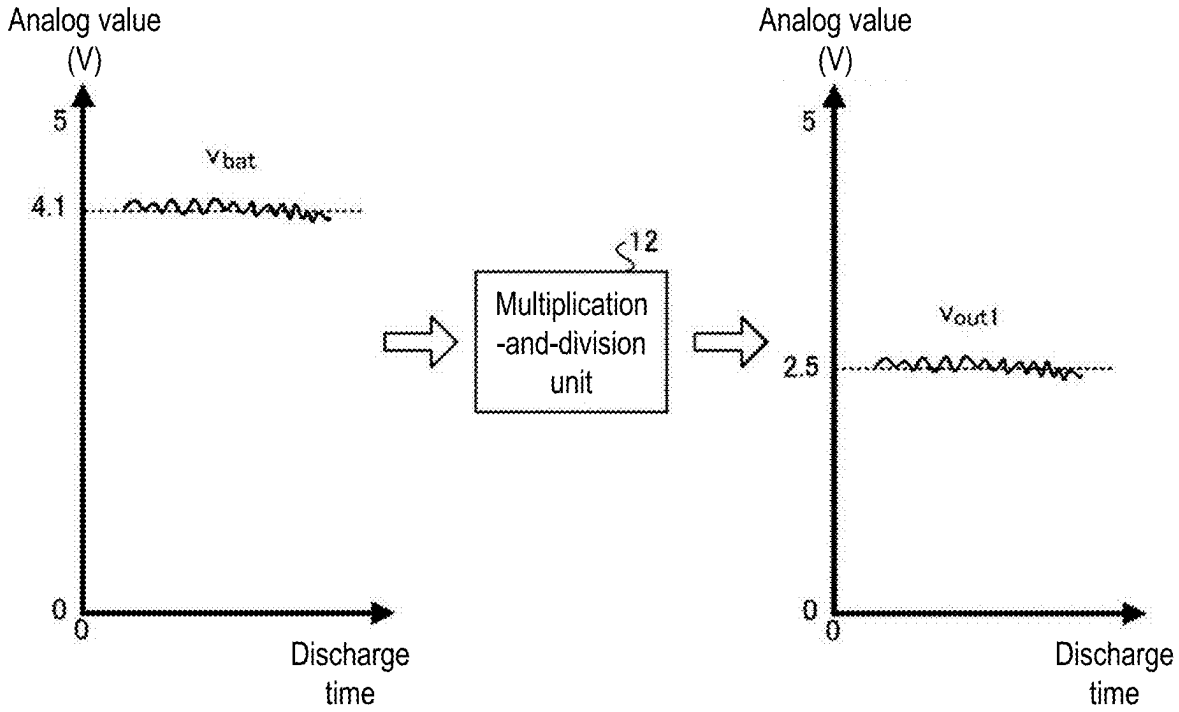

Analog value
(V)
5
4.1
Vbat
0
0
Discharge
time
12
Multiplication
-and-division
unit
Analog value
(V)
5
Vout1
2.5
0
0
Discharge
time

FIG. 4

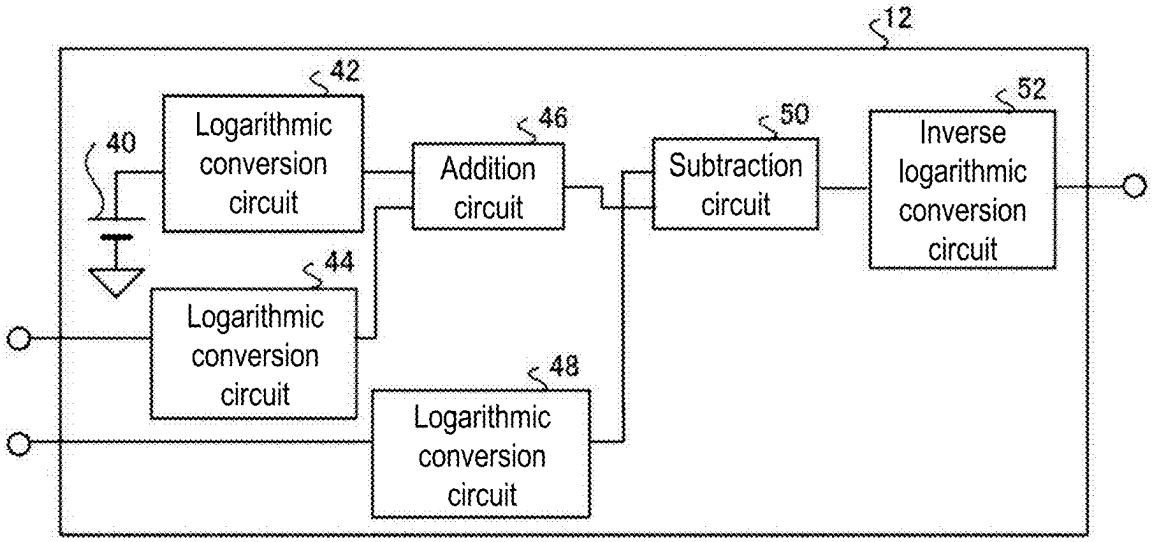

12
42
Logarithmic conversion circuit
40
46
Addition circuit
50
Subtraction circuit
52
Inverse logarithmic conversion circuit
44
Logarithmic conversion circuit
48
Logarithmic conversion circuit

FIG. 5

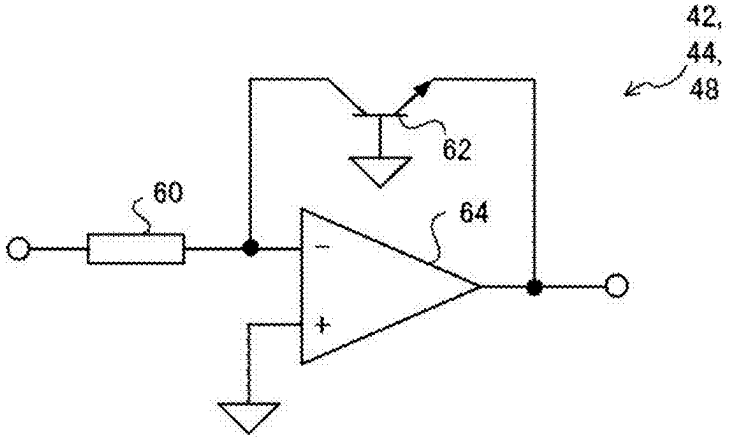

42,
44,
48
62
60
64
−
+

FIG. 6

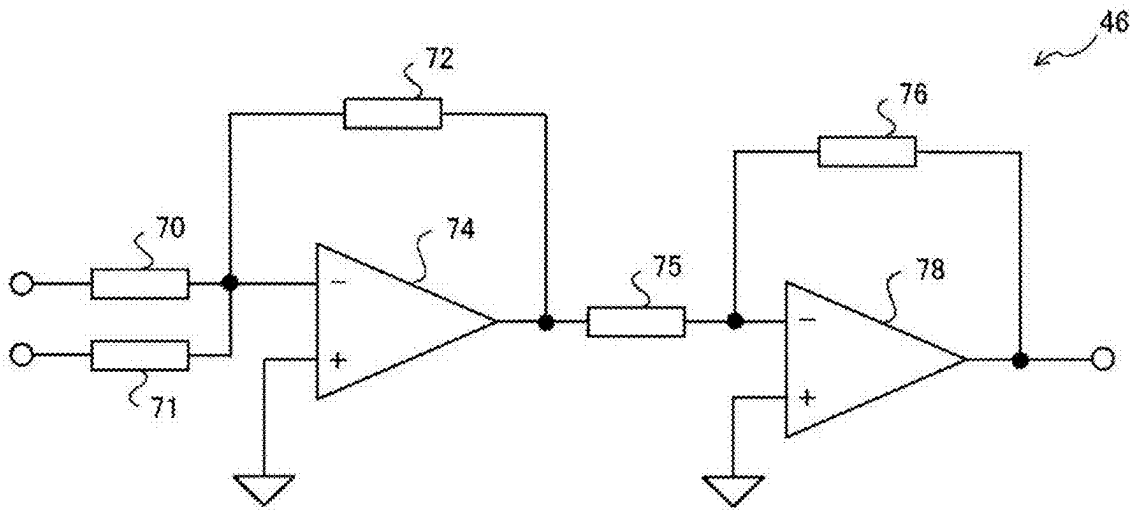


FIG. 7

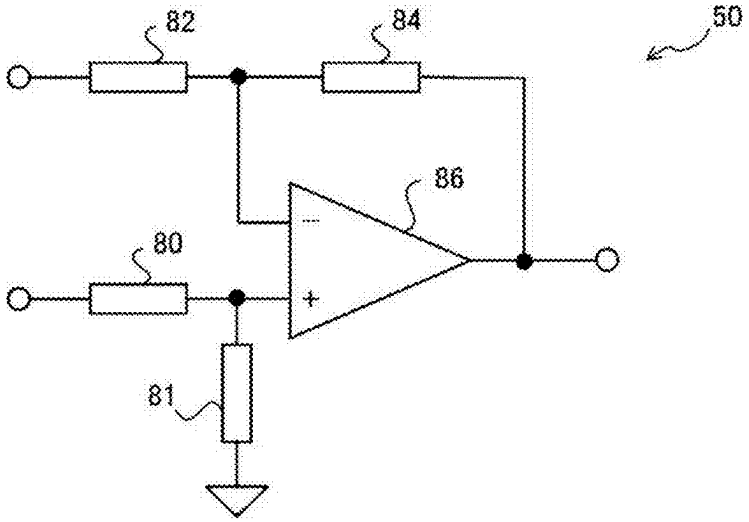


FIG. 8

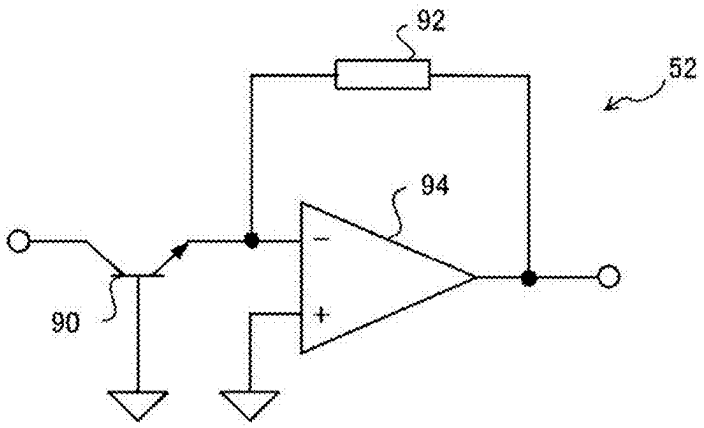

92
52
94
90
−
+

FIG. 9

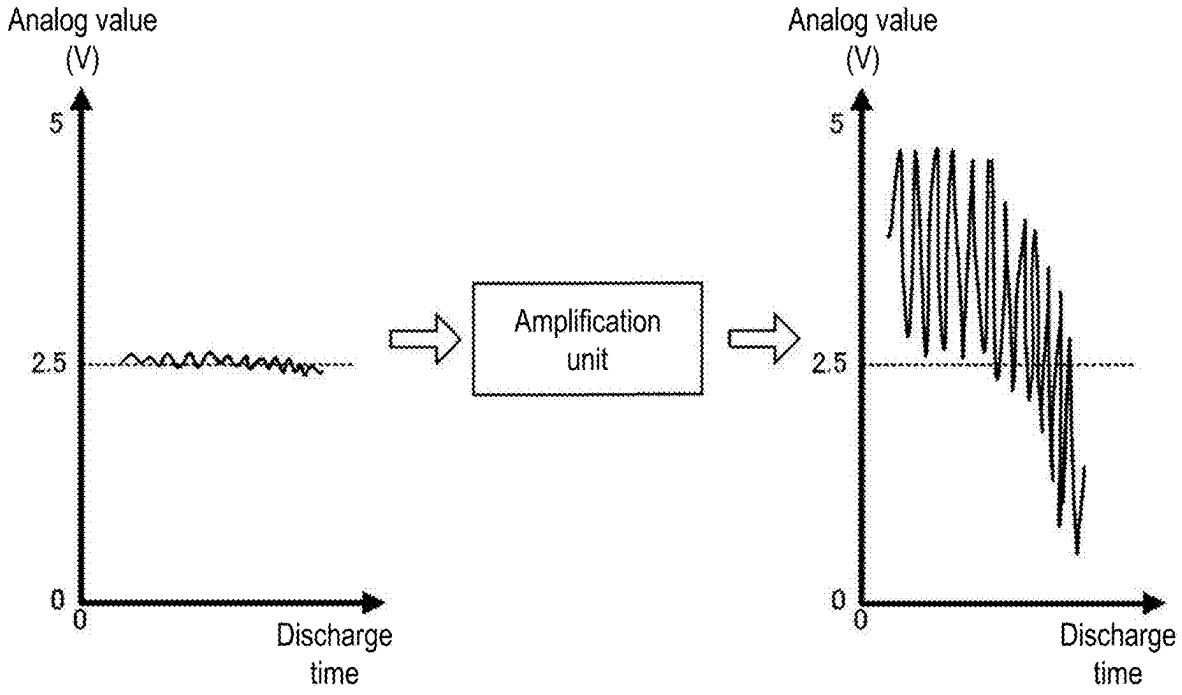

Analog value
(V)
5
2.5
0
0
Discharge
time
Amplification
unit
Analog value
(V)
5
2.5
0
0
Discharge
time

FIG. 10

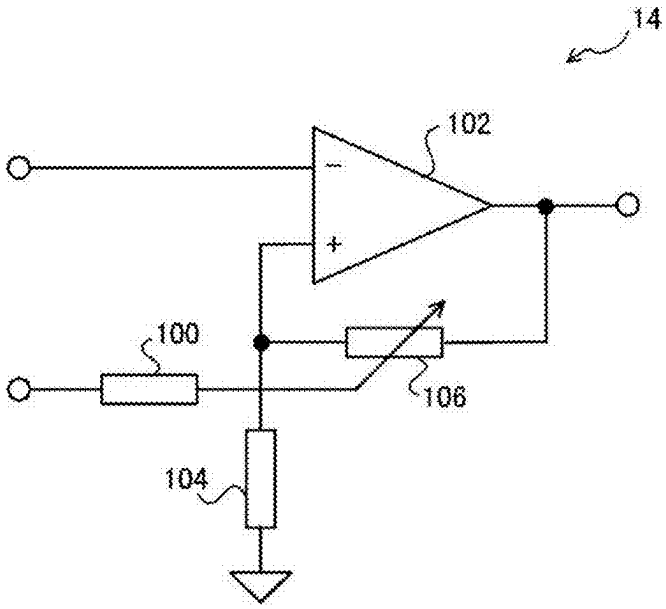


FIG. 11

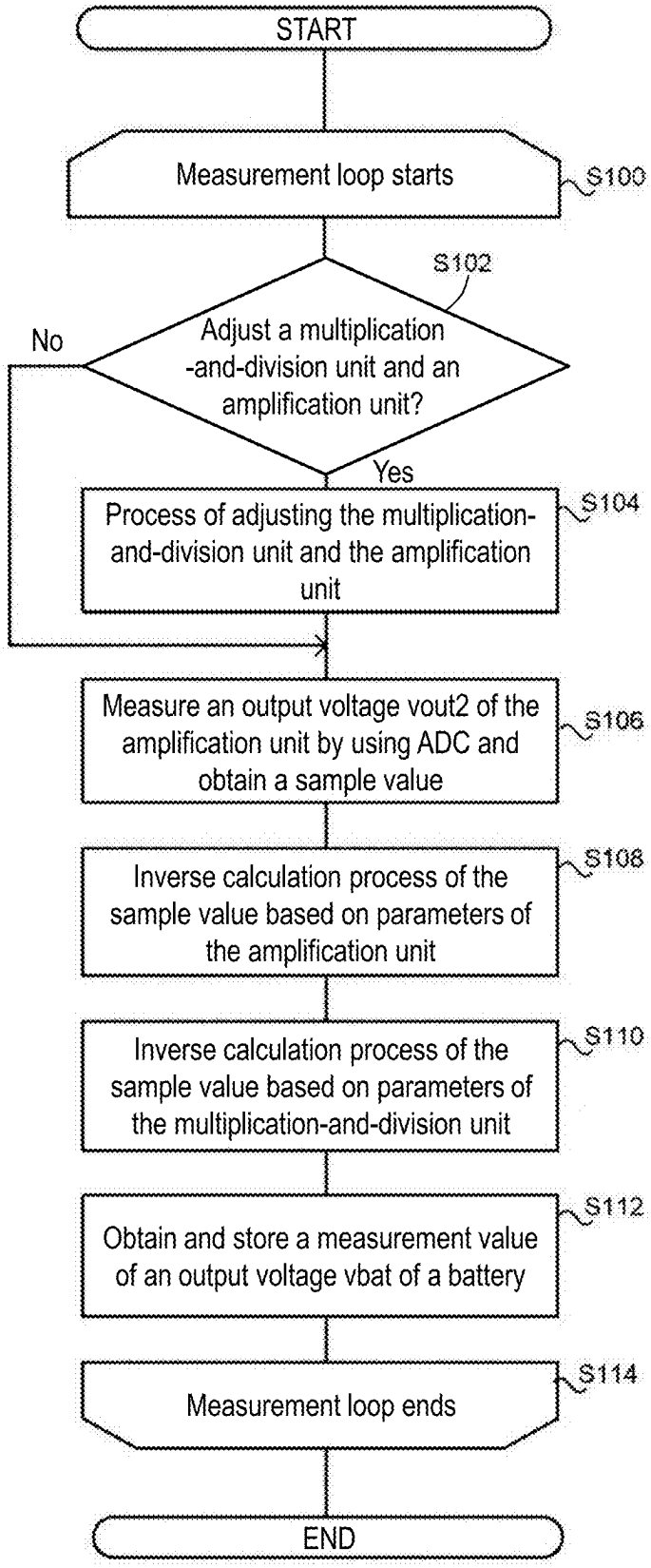

START
Measurement loop starts
S100
S102
Adjust a multiplication -and-division unit and an amplification unit?
No
Yes
Process of adjusting the multiplication-and-division unit and the amplification unit
S104
Measure an output voltage vout2 of the amplification unit by using ADC and obtain a sample value
S106
Inverse calculation process of the sample value based on parameters of the amplification unit
S108
Inverse calculation process of the sample value based on parameters of the multiplication-and-division unit
S110
Obtain and store a measurement value of an output voltage vbat of a battery
S112
Measurement loop ends
S114
END

FIG. 12

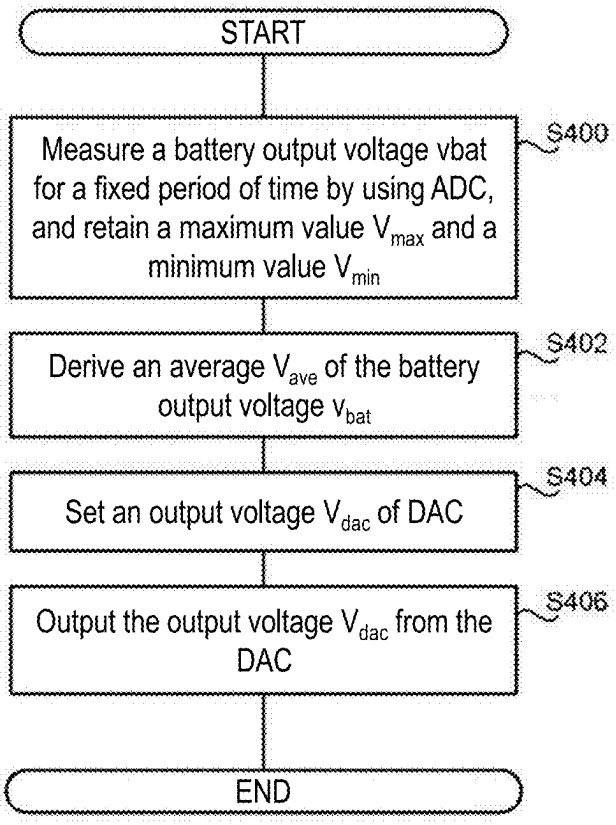

START
Measure a battery output voltage vbat for a fixed period of time by using ADC, and retain a maximum value V_{max} and a minimum value V_{min}
S400
Derive an average V_{ave} of the battery output voltage v_{bat}
S402
Set an output voltage V_{dac} of DAC
S404
Output the output voltage V_{dac} from the DAC
S406
END

FIG. 13

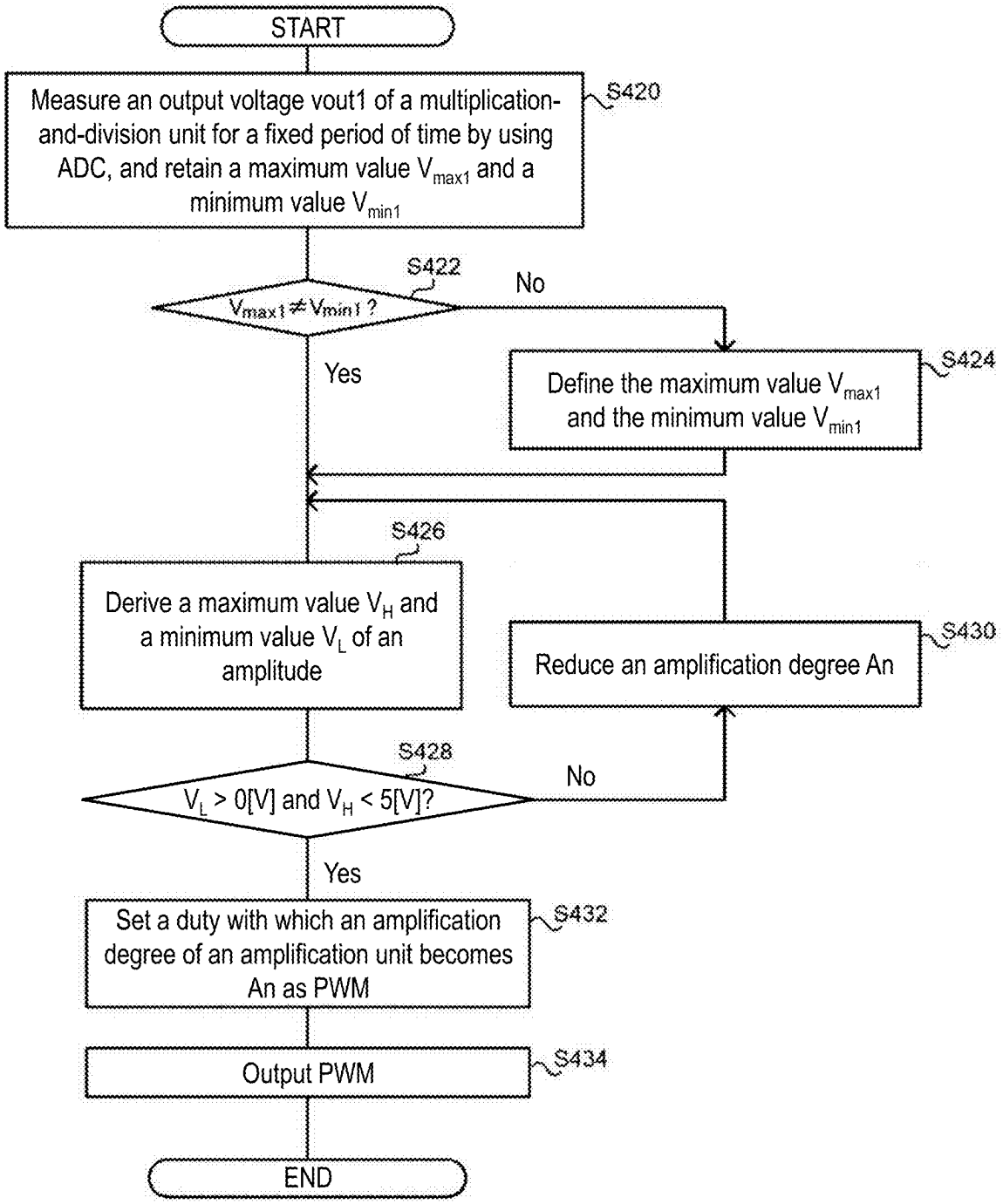

START
Measure an output voltage vout1 of a multiplication-and-division unit for a fixed period of time by using ADC, and retain a maximum value V_{max1} and a minimum value V_{min1}
S420
S422
$V_{max1} \neq V_{min1}$?
No
Yes
Define the maximum value V_{max1} and the minimum value V_{min1}
S424
S426
Derive a maximum value V_H and a minimum value V_L of an amplitude
Reduce an amplification degree An
S430
S428
$V_L > 0[V]$ and $V_H < 5[V]$?
No
Yes
Set a duty with which an amplification degree of an amplification unit becomes An as PWM
S432
Output PWM
S434
END

FIG. 14

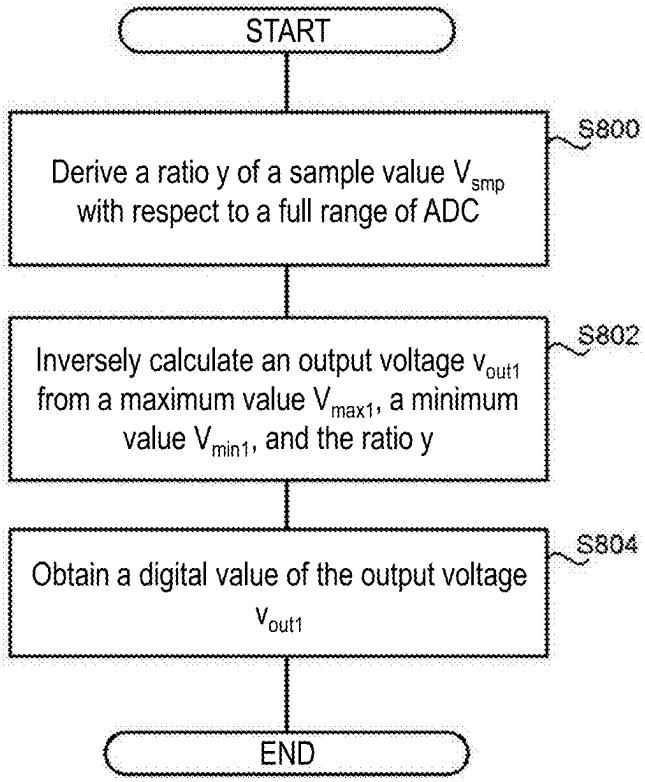

START
Derive a ratio y of a sample value V_{smp} with respect to a full range of ADC
S800
Inversely calculate an output voltage v_{out1} from a maximum value V_{max1}, a minimum value V_{min1}, and the ratio y
S802
Obtain a digital value of the output voltage V_{out1}
S804
END

FIG. 15

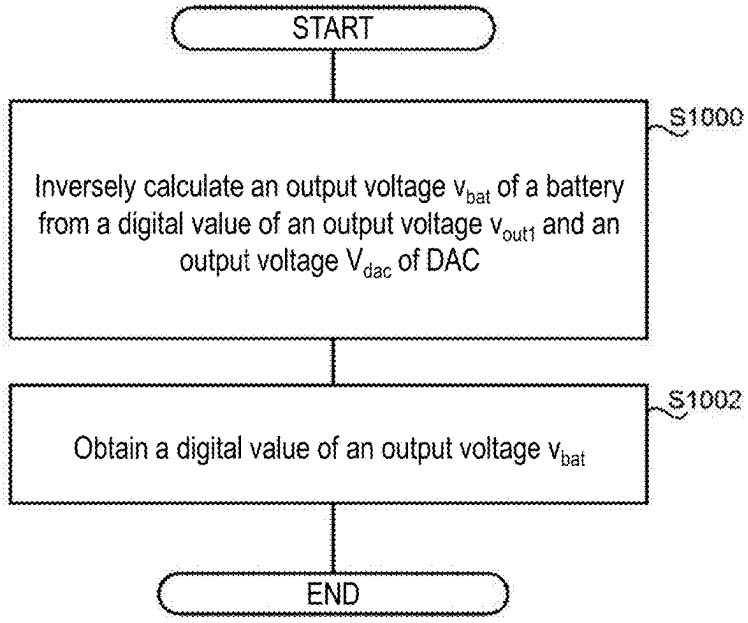

START
S1000
Inversely calculate an output voltage v_{bat} of a battery from a digital value of an output voltage v_{out1} and an output voltage V_{dac} of DAC
S1002
Obtain a digital value of an output voltage v_{bat}
END

FIG. 16

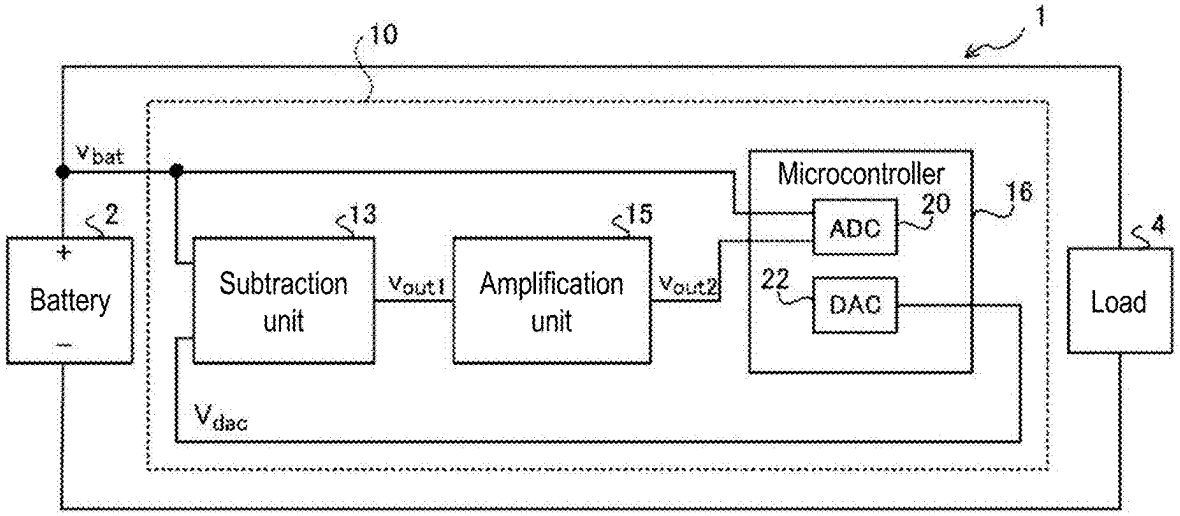

10
1
v_{bat}
2
+
Battery
−
13
Subtraction unit
v_{out1}
15
Amplification unit
v_{out2}
Microcontroller
ADC
20
16
22
DAC
4
Load
V_{dac}

FIG. 17

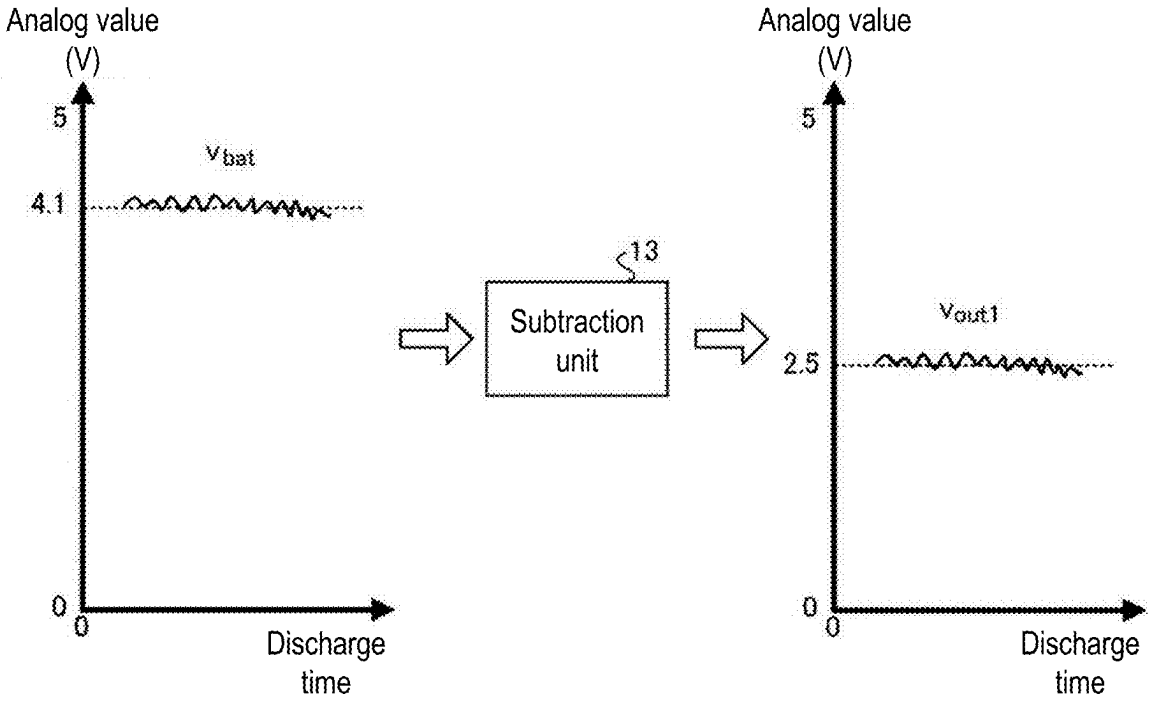

Analog value
(V)
5
4.1
V_{bat}
0
0
Discharge
time
13
Subtraction
unit
Analog value
(V)
5
V_{out1}
2.5
0
0
Discharge
time

FIG. 18

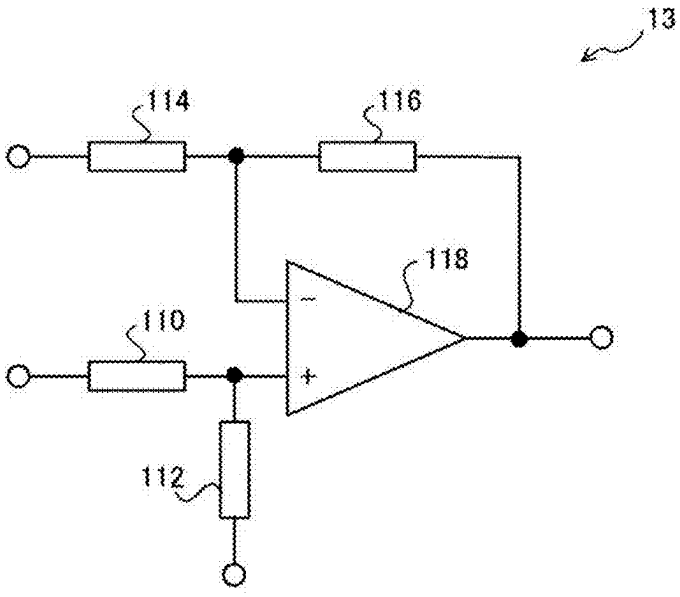


FIG. 19

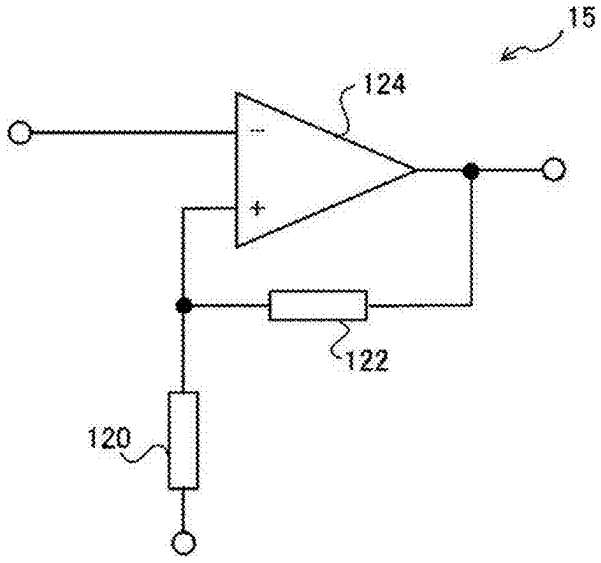


FIG. 20

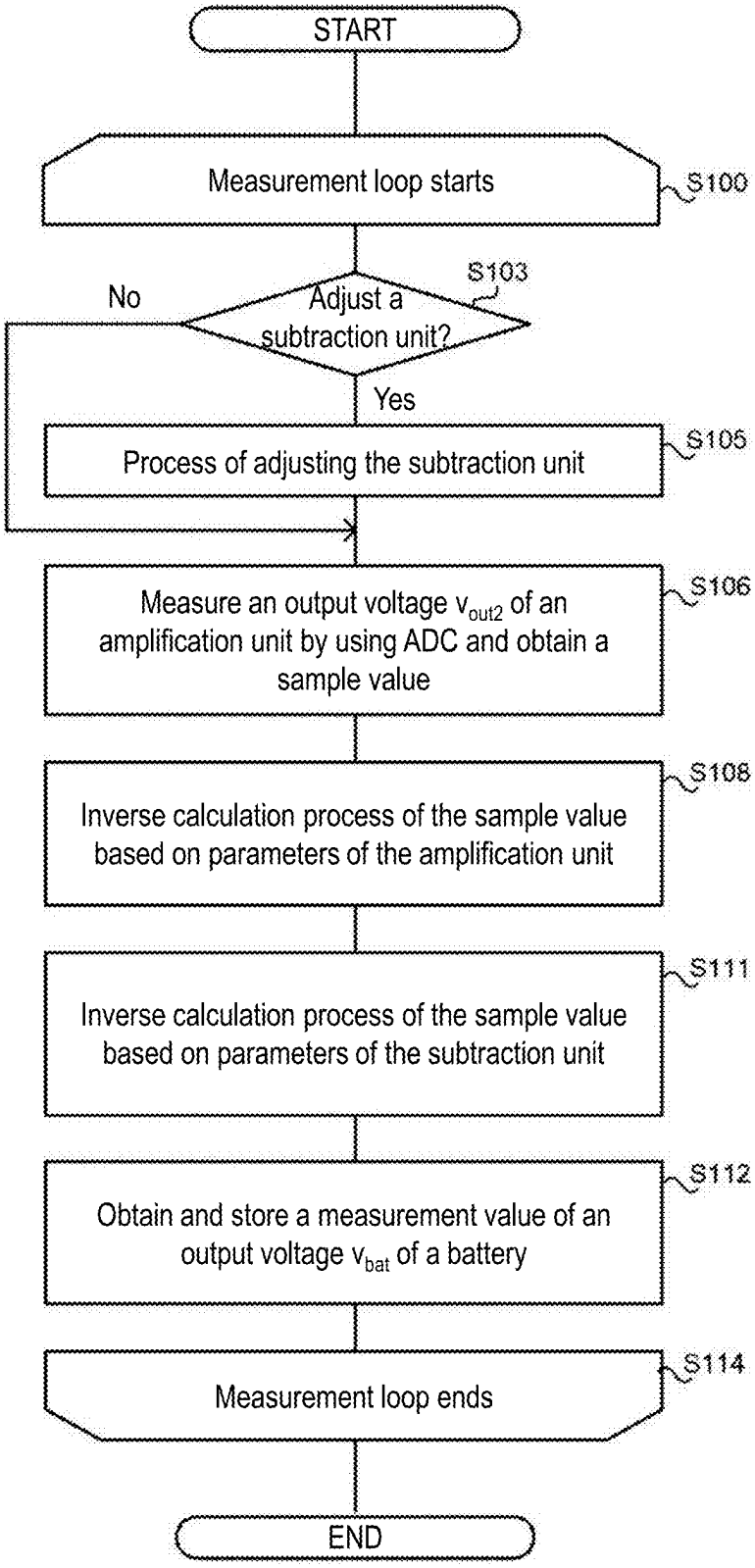

START
Measurement loop starts
S100
S103
No
Adjust a subtraction unit?
Yes
Process of adjusting the subtraction unit
S105
Measure an output voltage v_{out2} of an amplification unit by using ADC and obtain a sample value
S106
Inverse calculation process of the sample value based on parameters of the amplification unit
S108
Inverse calculation process of the sample value based on parameters of the subtraction unit
S111
Obtain and store a measurement value of an output voltage v_{bat} of a battery
S112
Measurement loop ends
S114
END

FIG. 21

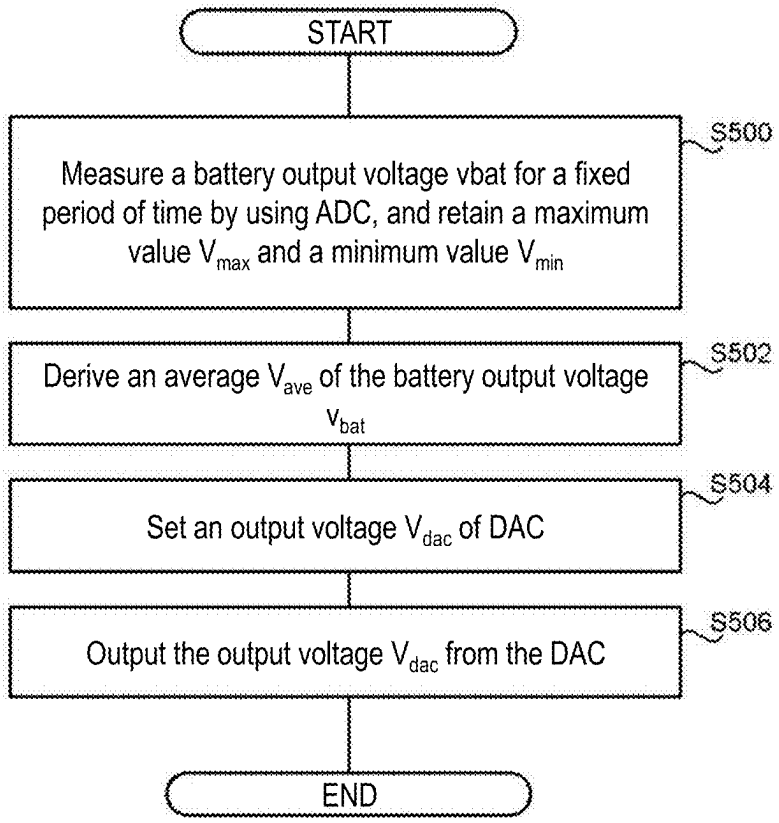

START
Measure a battery output voltage vbat for a fixed period of time by using ADC, and retain a maximum value V_{max} and a minimum value V_{min}
S500
Derive an average V_{ave} of the battery output voltage v_{bat}
S502
Set an output voltage V_{dac} of DAC
S504
Output the output voltage V_{dac} from the DAC
S506
END

FIG. 22

VOLTAGE DETECTION DEVICE AND VOLTAGE DETECTION METHOD

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority benefit of Japan application serial no. 2024-018981, filed on Feb. 9, 2024. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND

Technical Field

[0002] The disclosure relates to a voltage detection device and a voltage detection method.

Description of Related Art

[0003] A technology for detecting the output voltage of a battery by using an analog-to-digital converter (ADC) is known (see, for example, Japanese Patent Application Laid-open No. 2002-221544). The ADC serves for converting an analog voltage into a digital value. By connecting the output terminal of the battery to the input terminal of the ADC, the output voltage of the battery can be measured as a digital value.

SUMMARY

[0004] Changes of the output voltage of a battery include large changes over long periods and small changes over short periods. For example, in the changes in correspondence with the charge and discharge of the battery, the voltage changes so that the voltage decreases as the discharge time increases. Also, for example, in the changes in correspondence with fluctuations in the load connected to the battery, the voltage changes to fluctuate (oscillate) up and down in a relatively short period.

[0005] However, detecting both changes of the output voltage of the battery over long and short periods of time has not been easy, as such detection depends on the measurement range of the ADC used for detection, etc.

[0006] Provided is a voltage detection device and a voltage detection method capable of accurately detecting both changes of the output voltage of the battery over long and short periods of time.

[0007] To achieve the objective, a voltage detection device of the disclosure measures a voltage of a battery by using an analog-to-digital converter (ADC). The voltage detection device includes: a level shift unit, shifting a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC; an amplification unit, amplifying the voltage signal in which the voltage level is shifted by the level shift unit; the ADC, measuring the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and a derivation unit, deriving a voltage value of a voltage of the battery based on the sample signal output from the ADC.

[0008] Also, to achieve the objective, in a voltage detection method according to the disclosure, a processor included in a voltage detection device that measures a voltage of a battery by using an analog-to-digital converter (ADC) is configured to: shift, by using a level shift unit, a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC; amplify, by using an amplification unit, the voltage signal in which the voltage level is shifted by the level shift unit; measure, by using the ADC, the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and derive a voltage value of a voltage of the battery based on the sample signal output from the ADC.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a block diagram illustrating an example of a configuration of a voltage detection device according to a first embodiment.

[0010] FIG. **2** is a diagram illustrating changes of a voltage output from a battery.

[0011] FIG. **3** is a circuit diagram illustrating an example of a hardware configuration of a microcontroller.

[0012] FIG. **4** is a diagram illustrating the function of a multiplication-and-division unit.

[0013] FIG. **5** is a configuration diagram illustrating an example of a configuration of the multiplication-and-division unit.

[0014] FIG. **6** is a circuit diagram illustrating an example of the configuration of a logarithmic conversion circuit.

[0015] FIG. **7** is a circuit diagram illustrating an example of the configuration of an addition circuit.

[0016] FIG. **8** is a circuit diagram illustrating an example of the configuration of a subtraction circuit.

[0017] FIG. **9** is a circuit diagram illustrating an example of the configuration of an inverse logarithmic conversion circuit.

[0018] FIG. **10** is a diagram for describing the operation of an amplification unit.

[0019] FIG. **11** is a circuit diagram illustrating an example of the configuration of the amplification unit.

[0020] FIG. **12** is a flowchart illustrating an example of the flow of a measurement process according to the first embodiment.

[0021] FIG. **13** is a flowchart illustrating an example of the flow of the multiplication-and-division unit.

[0022] FIG. **14** is a flowchart illustrating an example of the flow of an amplification unit adjustment process.

[0023] FIG. **15** is a flowchart illustrating an example of the flow of the inverse calculation process of a sample value based on the parameters of the amplification unit.

[0024] FIG. **16** is a flowchart illustrating an example of the flow of the inverse calculation process of a sample value based on the parameters of the multiplication-and-division unit.

[0025] FIG. **17** is a block diagram illustrating an example of a voltage detection device according to a second embodiment.

[0026] FIG. **18** is a diagram for describing the operation of a subtraction unit.

[0027] FIG. **19** is a circuit diagram illustrating an example of the configuration of the subtraction unit.

[0028] FIG. **20** is a circuit diagram illustrating an example of the configuration of the amplification unit.

[0029] FIG. **21** is a flowchart illustrating an example of the flow of a measurement process according to the second embodiment.

[0030] FIG. **22** is a flowchart illustrating an example of the flow of a subtraction unit adjustment process.

DETAILED DESCRIPTION

[0031] According to the disclosure, both changes of the output voltage of the battery over long and short periods of time can be accurately detected.

[0032] The embodiments of the disclosure will be described in detail below with reference to the drawings. It should be noted that the following embodiments do not limit the technology of the disclosure.

First Embodiment

[0033] First, the configuration of a voltage detection device of the embodiment will be described. FIG. **1** illustrates a block diagram representing an example of the configuration of a voltage detection device **10** of the embodiment. As shown in FIG. **1**, the battery **2**, which is a detection target of the voltage detection device **10** of the embodiment, is connected to a load **4** and supplies voltage to the load **4**. The load **4** is driven by receiving the voltage supplied from the battery **2**. Examples of the load **4** may include various circuits and semiconductor devices.

[0034] The battery **2** of the embodiment is rechargeable, and can be used repeatedly by charging. Referring to FIG. **2**, the change of a voltage (output voltage) v_{bat} output from the battery **2** will be described. The voltage v_{bat} output from the battery **2** changes significantly over a long period of time (see time T in FIG. **2**) in response to charge and discharge (see change D in FIG. **2**). Specifically, the longer the discharge time, the smaller the voltage v_{bat} becomes. In addition, the voltage v_{bat} output from the battery **2** changes slightly (see change d in FIG. **2**) in a relatively short time (see time t in FIG. **2**) in accordance with the fluctuations of the load **4**. Specifically, in accordance with the fluctuations of the load **4**, the voltage v_{bat} fluctuates to the upper limit in a short period of time.

[0035] The voltage detection device **10** detects the voltage v_{bat} of the battery **2** that changes as described above. Specifically, the voltage detection device **10** detects a voltage signal corresponding to the voltage v_{bat} output from the battery **2** and measures the voltage value thereof. Here, the voltage signal output from the battery **2**, etc., may be simply referred to as "voltage". Also, the voltage output from various circuits, etc., may be referred to as "output voltage".

[0036] As shown in FIG. **1**, the voltage detection device **10** of the embodiment includes a multiplication-and-division unit **12**, an amplification unit **14**, and a microcontroller **16**.

[0037] The microcontroller **16** includes an analog-to-digital converter (ADC) **20**, a digital-to-analog converter (DAC) **22**, and a pulse width modulator (PWM) **24**, and has a function of controlling the operation of detecting the voltage of the battery **2** by using the voltage detection device **10**.

[0038] The ADC **20** is connected to the positive (+) side of the battery **2**, and the voltage output from the battery **2** is received by the ADC **20**. The ADC **20** is also connected to the multiplication-and-division unit **12**. Furthermore, the ADC **20** is connected to the amplification unit **14** and samples an output voltage v_{out2} output from the amplification unit **14**. As an example, in the embodiment, an ADC **20** with a measurement range of 5V is used.

[0039] The DAC **22** is connected to the multiplication-and-division unit **12** and has a function of controlling an output voltage v_{out1} output from the multiplication-and-division unit **12** by using an output voltage V_{dac} output from the DAC **22** (details in this regard will be described later). The output voltage V_{dac} of the DAC **22** is set by a multiplication-and-division unit adjustment process (see FIG. **13**) to be described in detail later.

[0040] The PWM **24** is connected to the amplification unit **14** and has a function of controlling a resistance value R_{var} of a variable resistor **106** (see FIG. **11**) of the amplification unit **14**, which will be described in detail later. Specifically, the resistance value R_{var} of the variable resistor **106** of the amplification unit **14** is controlled by an average voltage V_{pwm} output from the PWM **24**. The average voltage V_{pwm} of the PWM **24** is set by the amplification unit baking process (see FIG. **14**) to be described in detail later.

[0041] Such microcontroller **16** is, for example, as shown in FIG. **3**. The microcontroller **16** includes hardware components such as a central processing unit (CPU) **30**, a read-only memory (ROM) **32**, a random access memory (RAM) **34**, and a storage unit **36**. The CPU **30**, the ROM **32**, the RAM **34**, and the storage unit **36** are connected to enable transmission/reception of various information via buses (not shown) such as system buses, control buses. The CPU **30** is an example of a processor that controls the microcontroller **16**. The CPU **30** of the embodiment is an example of the derivation unit of the disclosure. The ROM **32** stores various programs in advance, including programs for performing the measurement process (details described later) to measure the output voltage v_{bat} of the battery **2**, which are executed by the CPU **30**. The RAM **34** temporarily stores various data. The storage unit **36** stores various information such as the measurement value of the output voltage v_{bat} of the battery **2**. As the storage unit **36**, various types of memories, etc., can be used, for example. The program for performing the measurement process may be stored in the storage unit **36**. The storage unit **36** may be provided other than the inside of the microcontroller **16**, that is, external to the microcontroller **16**. In this case, the measurement value is stored in the storage unit **36** by using the microcontroller **16** transmitting the measurement value obtained through measurement to the storage unit **36** provided externally.

[0042] The multiplication-and-division unit **12** is a circuit that performs multiplication or division on the output voltage v_{bat}, which is the analog voltage output from the battery **2**. Logarithmic conversion is performed on the input voltage, and voltages that are logarithmically converted are added or subtracted. Subsequently, by performing inverse logarithmic conversion on the voltage obtained through addition or subtraction, the result of performing multiplication or division on the original voltage can be obtained.

[0043] The multiplication-and-division unit **12** of the embodiment has a function to shift the level of the output voltage output from the battery **2**. Specifically, the multiplication-and-division unit **12** has a function to shift the voltage level of the voltage signal output from the battery **2** to the median of the measurement range of the ADC **20**. More specifically, as shown in FIG. **4**, the multiplication-and-division unit **12** outputs the output voltage v_{out1} in which the level (voltage value) of the output voltage v_{bat} is shifted, such that the average V_{ave} (4.1V in FIG. **4**) of the output voltage v_{bat} output from the battery **2** over a predetermined discharge time becomes the median (2.5V in FIG. **4**) of the measurement range of the ADC **20**. The multiplication-and-division unit **12** of the embodiment is an example of the level shift unit of the disclosure.

[0044] The specific configuration of the multiplication-and-division unit **12** of the embodiment is described. As shown in FIG. **5**, the multiplication-and-division unit **12** of the embodiment includes a constant voltage source **40**, a logarithmic conversion circuit **42**, a logarithmic conversion circuit **44**, an addition circuit **46**, a logarithmic conversion circuit **48**, a subtraction unit **50**, and an inverse logarithmic conversion circuit **52**.

[0045] The constant voltage source **40** serves to supply the voltage received by the logarithmic conversion circuit **42**, and outputs a voltage with a voltage value same as the median of the measurement range of the ADC **20** to the logarithmic conversion circuit **42**. As mentioned above, in the embodiment, an ADC **20** with a measurement range of 5V is used. In such case, the constant voltage source **40** is set to supply a power supply voltage V_{DD} of 2.5V. In the case where the voltage value of the constant voltage source **40** is greater than the median of the measurement range of the ADC **20**, the voltage value can be divided by a resistor or other elements, so that the voltage value after division becomes the median of the measurement range of the ADC **20**, and the power supply voltage V_{DD} after division can be supplied.

[0046] The logarithmic conversion circuits **42**, **44**, and **48** have similar configurations. FIG. **6** illustrates an example of the configuration of the logarithmic conversion circuit **42**, **44**, and **48**. The logarithmic conversion circuit **42**, **44**, and **48** include a resistor **60**, an NPN-type transistor **62**, and an operational amplifier **64**. The input terminal on the positive side of the operational amplifier **64** is connected to ground. In addition, an end of the resistor **60** is connected to the input terminal on the negative side of the operational amplifier **64**. As an example, in the embodiment, the resistance value of the resistor **60** is set to 25 kΩ. In the NPN-type transistor **62**, the collector is connected to the input terminal on the negative side of the operational amplifier **64**, and the emitter is connected to the output terminal of the operational amplifier **64**.

[0047] In the case of the logarithmic conversion circuit **42**, the other end of the resistor **60** is connected to the constant voltage source **40**. In addition, the output terminal of the operational amplifier **64** is connected to the addition circuit **46**. On the other hand, in the case of the logarithmic conversion circuit **44**, the other end of the resistor **60** is connected to the positive side of the battery **2**. In addition, the output terminal of the operational amplifier **64** is connected to the addition circuit **46**. Furthermore, in the case of the logarithmic conversion circuit **48**, the other end of the resistor **60** is connected to the DAC **22**. In addition, the output terminal of the operational amplifier **64** is connected to the subtraction unit **50**.

[0048] The addition circuit **46**, as shown in FIG. **7**, includes resistors **70**, **71**, **72**, **75**, **76**, and operational amplifiers **74**, **78**. In the embodiment, the resistance values of resistors **70**, **71**, **72**, **75**, **76** are set to be identical. As an example, in the embodiment, the resistance value is set to 10 kΩ.

[0049] The input terminal on the positive side of the operational amplifier **74** is connected to ground. In addition, an end of the resistor **70**, in which the other end is connected to the logarithmic conversion circuit **42**, is connected to the input terminal on the negative side of the operational amplifier **74**. In addition, an end of the resistor **71**, in which the other end is connected to the logarithmic conversion circuit **44**, is connected to the input terminal on the negative side of the operational amplifier **74**. Furthermore, the resistor **72** is connected between the input terminal on the negative side and the output terminal of the operational amplifier **74**. The output terminal of the operational amplifier **74** is connected to the input terminal on the negative side of the operational amplifier **78** through the resistor **75**. The input terminal on the positive side of the operational amplifier **78** is connected to ground. In addition, the resistor **76** is connected between the input terminal on the negative side and the output terminal of the operational amplifier **78**. The output terminal of the operational amplifier **78** is connected to the subtraction unit **50**.

[0050] The subtraction unit **50**, as shown in FIG. **8**, includes resistors **80**, **81**, **82**, **84**, and an operational amplifier **86**. In the embodiment, the resistance values of the resistors **80**, **81**, **82**, **84** are set to be identical, and are also identical to those of the resistors **70**, **71**, **72**, **75**, **76** in the addition circuit **46**. As an example, in the embodiment, the resistance value is set to 10 kΩ. The input terminal on the positive side of the operational amplifier **86** is connected to ground through the resistor **81**. In addition, an end of the resistor **80**, in which the other end is connected to the logarithmic conversion circuit **48**, is connected to the input terminal on the positive side of the operational amplifier **86**. On the other hand, an end of the resistor **82**, in which the other end is connected to the addition circuit **46**, is connected to the input terminal on the negative side of the operational amplifier **86**. The resistor **84** is connected between the input terminal on the negative side and the output terminal of the operational amplifier **86**. The output terminal of the operational amplifier **86** is connected to the inverse logarithmic conversion circuit **52**.

[0051] The inverse logarithmic conversion circuit **52**, as shown in FIG. **9**, includes an NPN-type transistor **90**, a resistor **92**, and an operational amplifier **94**. The input terminal on the positive side of the operational amplifier **94** is connected to ground. In addition, the emitter of the NPN-type transistor **90** is connected to the input terminal on the negative side of the operational amplifier **94**. The collector of the NPN-type transistor **90** is connected to the subtraction unit **50**. In addition, the resistor **92** is connected between the input terminal on the negative side and the output terminal of the operational amplifier **94**. The resistance value of the resistor **92** is set to be identical to the resistance values of the logarithmic conversion circuits **42**, **44**, **48**. As an example, in the embodiment, the resistance value of the resistor **92** is set to 25 kΩ. The output terminal of the operational amplifier **94** is output to the amplification unit **14**.

[0052] The voltage v_{out1} output from the multiplication-and-division unit **12** (inverse logarithmic conversion circuit **52**) is received by the amplification unit **14**. The output voltage v_{out1} output by the multiplication-and-division unit **12** is derived by using Equation (1) as follows, which utilizes the output voltage v_{bat} of the battery **2**, the power supply voltage V_{DD} of the constant voltage source **40**, and the output voltage V_{dac} of the DAC **22**. It should be noted

that Equation (1) is shown for the case where the power supply voltage V_{DD} of the constant voltage source **40** is 2.5V, as mentioned above.

[Formula 1]

$$v_{out1} = v_{bat} \times \frac{V_{DD}}{V_{dac}} = \frac{2.5}{V_{dac}} v_{bat} \quad (1)$$

[0053] The amplification unit **14** is a circuit that amplifies the amplitude of an analog voltage. In the embodiment, the amplification unit **14** has a variable amplification degree and serves to amplify the voltage v_{out1} output from the multiplication-and-division unit **12**. Specifically, as shown in FIG. **10**, the amplification unit **14** serves to amplify the amplitude of the changing output voltage v_{bat} output from the battery **2** by amplifying the voltage v_{out1}, and output the amplified voltage v_{out2}. More specifically, the amplification unit **14** amplifies the voltage v_{out1} so that the voltage v_{out2} within a predetermined discharge time does not exceed the measurement range of the ADC **20**, while effectively utilizing the measurement range. The amplification unit **14** in the embodiment is an example of the amplification unit of the disclosure.

[0054] In the embodiment, a non-inverting amplification unit is used as the amplification unit **14**. FIG. **11** illustrates a circuit diagram of an example of the configuration of the amplification unit **14** in the embodiment. As shown in FIG. **11**, the amplification unit **14** in the embodiment includes resistors **100**, **104**, an operational amplifier **102**, and a variable resistor **106**. The variable resistor **106** is connected between the input terminal on the positive side and the output terminal of the operational amplifier **102**. In the embodiment, a variable resistor whose resistance value can be controlled by using voltage is used as the variable resistor **106**. Specifically, an analog photocoupler using a cadmium sulfide (CdS) cell is used as the variable resistor **106**.

[0055] In addition, the input terminal on the positive side of the operational amplifier **102** is connected to ground through the resistor **104**. The resistance value of the resistor **104** is set to be the same as the resistance value of the analog photocoupler at the time when the voltage (5V in the embodiment) of the full range of the ADC **20** is received by the variable resistor **106** as an analog photocoupler. Due to the properties of the analog photocoupler, the measurement values may differ. Therefore, the resistance value of the resistor **104** is determined after measuring the properties of the analog photocoupler. The resistor **100** is connected to the PWM **24** and serves as a resistor to prevent overcurrent from flowing into the light-emitting diode (LED) used in the analog photocoupler of the variable resistor **106**. The resistance value of the resistor **100** is determined according to the specification of the analog photocoupler. On the other hand, the input terminal on the negative side of the operational amplifier **102** is connected to the inverse logarithmic conversion circuit **52** of the multiplication-and-division unit **12**.

[0056] An amplification degree A of the amplification unit **14** is determined by a resistance value R of the resistor **104** and the resistance value R_{var} of the variable resistor **106**, as shown in Equation (2) in the following. As mentioned above, the resistance value R_{var} of the variable resistor **106** is controlled by the average voltage V_{pwm} output from the PWM **24** of the microcontroller **16**.

[Formula 2]

$$A = 1 + \frac{R_{var}}{R} \quad (2)$$

[0057] The output voltage v_{out2} output from the amplification unit **14** is received by the ADC **20** of the microcontroller **16** and sampled by the ADC **20**. According to Equations (1) and (2) above, the output voltage v_{out2} output from the amplification unit **14** when the output voltage v_{out1} of the multiplication-and-division unit **12** is received by the amplification unit **14** is calculated by Equation (3) as follows:

[Formula 3]

$$v_{out2} = A \times v_{out1} = \left(1 + \frac{R_{var}}{R}\right) \frac{2.5}{V_{dac}} v_{bat} \quad (3)$$

[0058] Then, the measurement process for measuring the output voltage v_{bat} of the battery **2** by using the voltage detection device **10** of the embodiment will be described. In the embodiment, as preliminary preparation before performing the measurement process, the microcontroller **16** retains information representing the correspondence relationship of the value of the amplification degree of the amplification unit **14** with respect to the percentage of the duty of the PWM **24**. The information representing the correspondence relationship can be obtained by deriving the amplification degree An through actually inputting the average voltage V_{pwm} of the PWM **24** to the variable resistor **106** (photocoupler) of the amplification unit **14** while varying the duty of the PWM **24**, and measuring the resistance value R_{var} of the photocoupler at this time. In the embodiment, the information representing the correspondence relationship obtained by actually measuring the resistance value R_{var} is stored in advance in the storage unit **36** of the microcontroller **16**.

[0059] FIG. **12** illustrates a flowchart representing an example of the flow of the measurement process executed by the microcontroller **16** of the voltage detection device **10**. In the embodiment, the measurement process shown in FIG. **12** is executed by the CPU **30** of the microcontroller **16** executing a program (not shown) stored in the ROM **32**.

[0060] As shown in FIG. **12**, the measurement of the output voltage v_{bat} of the battery **2** is performed by repeating the processes of Steps S**100** to S**114**.

[0061] As shown in FIG. **12**, first, in Step S**100**, a measurement loop is started.

[0062] Then, in Step S**102**, the CPU **30** determines whether to adjust the multiplication-and-division unit **12** and the amplification unit **14**. Regarding whether to adjust the multiplication-and-division unit **12** and the amplification unit **14**, an arbitrary condition, such as the elapsed time from the previous adjustment, the fluctuation of the output voltage v_{bat} of the battery **2**, etc., may be set, and the CPU **30** may perform the determination based on the set condition. If the multiplication-and-division unit **12** and the amplification unit **14** are not to be adjusted, the process of Step S**102**

results in a negative determination, and the flow proceeds to Step S**106**. On the other hand, if the multiplication-and-division unit **12** and the amplification unit **14** are to be adjusted, the determination in Step S**102** results in a positive determination, and the flow proceeds to Step S**104**.

[0063] In Step S**104**, the CPU **30** executes the process of adjusting the multiplication-and-division unit **12** and the amplification unit **14**, the details of which will be described later.

[0064] Then, in Step S**106**, the CPU **30** measures the output voltage v_{out2} of the amplification unit **14** by using the ADC **20** and obtains a sampling value. As mentioned above, the output voltage v_{out2} of the amplification unit **14** is the result of the output voltage v_{bat} of the battery **2** being changed through the multiplication-and-division unit **12** and the amplification unit **14**.

[0065] Then, in Step S**108**, the CPU **30** performs an inverse calculation process (details described later) of inversely calculating the sample value of the output voltage v_{out2} based on the parameters of the amplification unit **14**, and converts the inversely calculated value to the voltage value before being received by the amplification unit **14**

[0066] Then, in Step S**110**, the CPU **30** performs the inverse calculation process (details described later) to inversely calculate the sample value obtained in Step S**108** based on the parameters of the multiplication-and-division unit **12**, and converts the inversely calculated value to the voltage value before being received by the multiplication-and-division unit **12**.

[0067] Then, in Step S**112**, the CPU **30** obtains a measurement value (digital value) of the output voltage v_{bat} of the battery **2** and stores the measurement value in the storage unit **36**.

[0068] By repeating (looping) the processes of Steps S**102** to S**112**, multiple measurement values of the output voltage v_{bat} of the battery **2** are obtained.

[0069] In the case where the termination condition is satisfied, in Step S**114**, the CPU **30** terminates the measurement loop. When the process of Step S**114** is completed, the measurement process shown in FIG. **12** is ended.

[0070] Furthermore, the adjustment process of the multiplication-and-division unit **12** and the amplification unit **14**, which is executed in Step S**104** of the measurement process of FIG. **12**, will be described. The adjustment process includes two processes, that is, a multiplication-and-division unit adjustment process for adjusting the multiplication-and-division unit **12**, and an amplification unit adjustment process for adjusting the amplification unit **14**.

[0071] First, the multiplication-and-division unit adjustment process for adjusting the multiplication-and-division unit **12** will be described. FIG. **13** shows a flowchart representing an example of the flow of the multiplication-and-division unit adjustment process executed by the microcontroller **16** of the voltage detection device **10**.

[0072] In Step S**400** of FIG. **13**, the CPU **30** measures the output voltage v_{bat} of the battery **2** for a fixed period of time, and obtains and retains a maximum value V_{max} and a minimum value V_{min} of the output voltage v_{bat} as digital values.

[0073] Then, in Step S**402**, the CPU **30** derives the average V_{ave} of the output voltage v_{bat} of the battery **2**. In the embodiment, the CPU **30** derives the average V_{ave} by using Equation (4) as follows to calculate the average of the maximum value V_{max} and the minimum value V_{min} of the output voltage v_{bat}.

[Formula 4]

$$V_{ave} = \frac{V_{max} + V_{min}}{2} \tag{4}$$

[0074] Then, in Step S**404**, the CPU **30** sets the output voltage V_{dac} of the DAC **22**. In the embodiment, the output voltage V_{dac} of the DAC **22** is set to be the same as the average V_{ave} of the output voltage v_{bat} of the battery **2**.

[0075] Then, in Step S**406**, the CPU **30** starts the output of the output voltage V_{dac} from the DAC **22**. When the process of Step S**406** is completed, the multiplication-and-division unit adjustment process shown in FIG. **13** is finished.

[0076] Then, the amplification unit adjustment process for adjusting the amplification unit **14** will be described. FIG. **14** shows a flowchart representing an example of the flow of the amplification unit adjustment process executed by the microcontroller **16** of the voltage detection device **10**.

[0077] In Step S**420** of FIG. **14**, the CPU **30** measures the output voltage v_{out1} of the multiplication-and-division unit **12** for a fixed period of time, obtains and retains the maximum value V_{max1} and the minimum value V_{min1} of the output voltage v_{out1} as digital values.

[0078] Then, in Step S**422**, the CPU **30** determines whether the maximum value V_{max1} and the minimum value V_{min1} are different values ($V_{max1} \cdot V_{min1}$). In the case where the maximum value V_{max1} and the minimum value V_{min1} are not different values, the determination in Step S**422** results in a negative determination, and the flow proceeds to Step S**424**.

[0079] In Step S**424**, the CPU **30** defines the maximum value V_{max1} and the minimum value V_{min1} to be different values, and then proceeds to Step S**426**. Specifically, the CPU **30** defines the maximum value V_{max1} by using Equation (5) as follows, and defines the minimum value V_{min1} by using Equation (6) as follows. For "x" in Equations (5) and (6) below, the minimum value that can be expressed as a digital value by the ADC **20** is used. The value of "x" is determined in advance according to the expected variation amount in the output voltage v_{out1} of the multiplication-and-division unit **12**.

[Formula 5]

$$V_{max1} = V_{max1} + x \tag{5}$$

$$V_{min1} = V_{min1} - x \tag{6}$$

[0080] Meanwhile, in the case where the maximum value V_{max1} and the minimum value V_{min1} are different values, the determination in Step S**422** results in a positive determination, and the flow proceeds to Step S**426**. In step S**426**, the CPU **30** derives a maximum value V_H and a minimum value V_L of the amplitude when amplified by the amplification degree An of the amplification unit **14**, which has been obtained in advance during preparation. Specifically, the

CPU **30** derives the maximum value V_H of the amplitude by using Equation (7) as follows, and derives the minimum value V_L of the amplitude by using Equation (8) as follows.

[Formula 6]

$$V_H = V_{max1} + (V_{max1} - V_{min1}) \times \left(\frac{A_n}{2}\right) \quad (7)$$

$$V_L = V_{min1} + (V_{max1} - V_{min1}) \times \left(\frac{A_n}{2}\right) \quad (8)$$

[0081] Then, in Step S**428**, the CPU **30** determines whether the amplitude when amplified by the amplification degree An of the amplification unit **14** fits within the measurement range of the ADC **20**. In the embodiment, since the measurement range of the ADC **20** is 0V to 5V, the CPU **30** specifically determines whether the condition that the minimum value V_L of the amplitude is greater than 0V (V_L>0) and the maximum value V_H of the amplitude is less than 5V (V_H<5) is satisfied. If the condition is not satisfied, the determination in Step S**428** results in a negative determination, and the flow proceeds to Step S**430**. In this case, since the output voltage v_{out2} of the amplification unit **14** amplified by the set amplification degree An does not fit within the measurement range of the ADC **20**, in Step S**430**, the CPU **30** changes the amplification degree An from the current value to a smaller value, and then returns to Step S**426**. As a result, the process of Step S**426** is performed again with the amplification degree An being reset to a smaller value.

[0082] On the other hand, in the case where the minimum value V_L of the amplitude derived in Step S**426** is greater than 0V and the maximum value V_H of the amplitude is less than 5V, the determination in Step S**428** results in a positive determination, and the flow proceeds to Step S**432**.

[0083] Then, in Step S**432**, the CPU **30** derives the duty of the PWM **24** corresponding to the amplification degree An currently set in the amplification unit **14** from the information representing the correspondence relationship described above, and sets the duty in the PWM **24**.

[0084] Then, in Step S**434**, the CPU **30** starts signal output from the PWM **24**. As described above, the average voltage V_{pwm} of the output voltage output from the PWM **24** changes the resistance value of the variable resistor **106** (photocoupler) of the amplification unit **14**, and the amplification unit with the amplification degree An that satisfies the condition is realized. When the process of Step S**434** is completed, the amplification unit adjustment process shown in FIG. **14** is completed.

[0085] Furthermore, the inverse calculation process of the sample value based on the parameters of the amplification unit **14**, which is executed in Step S**108** of the measurement process in FIG. **12**, will be described. FIG. **15** shows a flowchart representing an example of the flow of the inverse calculation process of the sample value based on the parameters of the amplification unit **14**, executed by the microcontroller **16** of the voltage detection device **10**.

[0086] In Step S**800** of FIG. **15**, the CPU **30** derives a ratio y of a sample value V_{smp} obtained by the ADC **20** to the full range of the ADC **20**. Since the full range of the ADC **20** is 5V, in the embodiment, the CPU **30** derives the ratio y by using Equation (9) as follows.

[Formula 7]

$$y = \frac{V_{smp}}{5} \quad (9)$$

[0087] Then, in Step S**802**, the CPU **30** inversely calculates the voltage received by the amplification unit **14**, that is, the output voltage v_{out1} of the multiplication-and-division unit **12**, from the maximum value V_{max1} and the minimum value V_{min1} of the output voltage v_{out1} of the multiplication-and-division unit **12**, and the ratio y derived in Step S**800** above. In the embodiment, the CPU **30** inversely calculates the output voltage v_{out1} by using Equation (10) as follows.

[Formula 8]

$$v_{out1} = (V_{max1} - V_{min1}) \times y + V_{min1} \quad (10)$$

[0088] Then, in Step S**804**, the CPU **30** obtains the output voltage v_{out1} derived in Step S**802** above as a digital value of the output voltage v_{out1}. When the process of Step S**804** is completed, the inverse calculation process of the sample value based on the parameters of the amplification unit **14** shown in FIG. **15** is finished.

[0089] Furthermore, the inverse calculation process of the sample value based on the parameters of the multiplication-and-division unit **12**, which is executed in Step S**110** of the measurement process in FIG. **12**, will be described. FIG. **16** shows a flowchart representing an example of the flow of the inverse calculation process of the sample value based on the parameters of the multiplication-and-division unit **12**, executed by the microcontroller **16** of the voltage detection device **10**.

[0090] In Step S**1000** of FIG. **16**, the CPU **30** inversely calculates the output voltage v_{bat} of the battery **2** from the digital value of the output voltage Vout of the multiplication-and-division unit **12** obtained by the inverse calculation process of FIG. **15** described above, and the output voltage V_{dac} of the DAC **22**. In the embodiment, the CPU **30** inversely calculates the output voltage v_{bat} by using Equation (11) as follows, which is derived from Equation (1) mentioned above.

[Formula 9]

$$v_{bat} = v_{out1} \times \frac{V_{dac}}{2.5} \quad (11)$$

[0091] Then, in Step S**1002**, the CPU **30** obtains the output voltage v_{bat} derived in Step S**1000** above as a digital value of the output voltage v_{bat}. When the process of Step S**1002** is completed, the inverse calculation process of the sample value based on the parameters of the multiplication-and-division unit **12** shown in FIG. **16** is finished.

[0092] In this way, in the measurement process shown in FIG. **12**, one measurement value of the output voltage v_{bat} of the battery **2** is obtained by the processes of Steps S**102** to S**112**, and measurement values for the number of times of the measurement loop are obtained. With the measurement values for the number of times of the measurement loop, it is possible to accurately detect the changes (amplitude) in the output voltage v_{bat} over a short period of time (see time t in FIG. **2**) in response to the fluctuations of the load **4**, such as the change d shown in FIG. **2** described above.

[0093] Furthermore, in the embodiment, the voltage detection device **10** performs the measurement process and obtains the measurement values of the output voltage v_{bat} of the battery **2** for the number of times of the measurement loop at the respective predetermined timings, such as at the timings corresponding to the elapsed time since the charging the battery **2** is completed, or at timings corresponding to the operating state of the load **4** By connecting the measurement values of the output voltage v_{bat} of the battery **2** for the number of times of the measurement loop obtained at the respective predetermined timings, it is possible to detect changes (see time T in FIG. **2**) for a long period of time corresponding to the charge and discharge of the battery **2**, such as the change D shown in FIG. **2** described above.

Second Embodiment

[0094] FIG. **17** illustrates a block diagram representing an example of the configuration of a voltage detection device **10** of the embodiment. As shown in FIG. **17**, the voltage detection device **10** of the embodiment includes a subtraction unit **13** and an amplification unit **15**, which serve as an example of a circuit having two functions, i.e., subtraction and amplification, in place of the multiplication-and-division unit **12** and the amplification unit **14** of the voltage detection device **10** of the first embodiment (see FIG. **1**). Additionally, the microcontroller **16** of the embodiment differs from the microcontroller **16** of the first embodiment (see FIG. **1**) in that the microcontroller **16** of the embodiment does not include the PWM **24**.

[0095] The subtraction unit **13** is a circuit that performs subtraction of the analog voltage output from the battery **2**. The subtraction unit **13** of the embodiment has a function of shifting the level of the output voltage v_{bat} output from the battery **2** by subtracting the output voltage V_{dac} of the DAC **22** from the output voltage v_{bat} of the battery **2**. Specifically, the subtraction unit **13** has a function of shifting the voltage level of the voltage signal output from the battery **2** to the median of the measurement range of the ADC **20**. More specifically, as shown in FIG. **18**, the subtraction unit **13** outputs the output voltage v_{out1} with a shifted level (voltage value) of the output voltage v_{bat}, so that the average V_{ave} (4.1V in FIG. **18**) of the output voltage v_{bat} output from the battery **2** for the predetermined discharge time becomes the median of the ADC **20** (2.5V in FIG. **18**). The subtraction unit **13** of the embodiment is an example of the level shift unit of the disclosure.

[0096] Thus, the output voltage v_{out1} output from the subtraction unit **13** is obtained by Equation (12) as follows.

[Formula 10]

$$v_{out} = v_{bat} - v_{dac} \tag{12}$$

[0097] The specific configuration of the subtraction unit **13** of the embodiment is described. FIG. **19** illustrates an example of the configuration of the subtraction unit **13**. The subtraction unit **13** includes resistors **110**, **112**, **114**, **116**, and an operational amplifier **118**. In the embodiment, the resistance values of the resistors **110**, **112**, **114**, **116** are set to be identical. The input terminal on the positive side of the operational amplifier **118** is connected to the DAC **22** through the resistor **110**. Additionally, the input terminal on the positive side of the operational amplifier **118** is connected to the reference voltage of the subtraction unit **13** through the resistor **112**. In the embodiment, the reference voltage of the subtraction unit **13** is set as the voltage value of the median of the measurement range of the ADC **20**. On the other hand, the input terminal on the negative side of the operational amplifier **118** is connected to the positive side of the battery **2** through the resistor **114**. In addition, the resistor **116** is connected between the input terminal on the negative side and the output terminal of the operational amplifier **118**. Furthermore, the output terminal of the operational amplifier **118** is connected to the amplification unit **15**.

[0098] The amplification unit **15** is a circuit that amplifies the amplitude of an analog voltage. The amplification unit **15** of the embodiment serves to amplify the voltage v_{out1} output from the subtraction unit **13**. Specifically, similar to the amplification unit **14** of the first embodiment, as shown in FIG. **10**, the amplification unit **15** serves to amplify the amplitude in which the output voltage v_{bat} output from the battery **2** changes by amplifying the voltage v_{out1} and output the amplified voltage v_{out2}. More specifically, the amplification unit **15** amplifies the voltage v_{out1} so that the voltage v_{out2} within a predetermined discharge time does not exceed the measurement range of the ADC **20**, while effectively utilizing the measurement range. The amplification unit **15** in the embodiment is an example of the amplification unit of the disclosure. The amplification unit **15** may have a variable amplification degree or a fixed amplification degree.

[0099] In the embodiment, a non-inverting amplification unit is used as the amplification unit **15**. FIG. **20** illustrates a circuit diagram of an example of the configuration of the amplification unit **15** in the embodiment. As shown in FIG. **20**, the amplification unit **15** in the embodiment includes resistors **120**, **122**, and an operational amplifier **118**. The input terminal on the negative side of the operational amplifier **124** is connected to the subtraction unit **13**. Meanwhile, the input terminal on the positive side of the operational amplifier **124** is connected to the reference voltage of the amplification unit **15** through the resistor **120**. In the embodiment, the reference voltage of the amplification unit **15** is set to the voltage value of the median of the measurement range of the ADC **20**. In addition, the resistor **122** is connected between the input terminal on the positive side and the output terminal of the operational amplifier **124**.

[0100] The output terminal of the operational amplifier **124** is connected to the ADC **20** of the microcontroller **16**. The output voltage v_{out2} output from the amplification unit

15 is received by the ADC **20** of the microcontroller **16** and sampled by the ADC **20**. The amplification degree of the amplification unit **15** is determined by the resistance value R**1** of the resistor **120** and the resistance value R**2** of the resistor **122**. The output voltage v_{out2} output from the amplification unit **15** is calculated according to Equation (13) in the following.

[Formula 11]

$$v_{out2} = \left(1 + \frac{R_2}{R_1}\right) v_{out1} \tag{13}$$

[0101] Then, the measurement process for measuring the output voltage v_{bat} of the battery **2** by using the voltage detection device **10** of the embodiment will be described.

[0102] FIG. **21** illustrates a flowchart representing an example of the flow of the measurement process executed by the microcontroller **16** of the voltage detection device **10**. The measurement process of the embodiment shown in FIG. **21** differs from the measurement process of the first embodiment (see FIG. **12**) in that the measurement process of the embodiment includes the processes of Steps S**103** and S**105** instead of Steps S**102** and S**104**.

[0103] As shown in FIG. **21**, in Step S**100**, when the measurement loop is started, in the next Step S**103**, the CPU **30** determines whether to adjust the subtraction unit **13**. Regarding whether to adjust the subtraction unit **13**, an arbitrary condition, such as the elapsed time from the previous adjustment, the fluctuation of the output voltage v_{bat} of the battery **2**, etc., may be set, and the CPU **30** may perform the determination based on the set condition. If the subtraction unit **13** is not to be adjusted, the process of Step S**103** results in a negative determination, and the flow proceeds to Step S**106**. Meanwhile, if the subtraction unit **13** is to be adjusted, the process of Step S**103** results in a positive determination, and the flow proceeds to Step S**105**.

[0104] In Step S**105**, the CPU **30** executes the process of adjusting the subtraction unit **13**, the details of which will be described later.

[0105] Then, in Step S**106**, the CPU **30** measures the output voltage v_{out2} of the amplification unit **15** by using the ADC **20** and obtains a sampling value, similar to the measurement process of the first embodiment.

[0106] Next, in Step S**108**, the CPU **30** performs an inverse calculation process of inversely calculating the sample value of the output voltage v_{out2} based on the parameters of the amplification unit **15**. In the embodiment, the CPU **30** inversely calculates the sample value of the output voltage v_{out2} by performing the inverse calculation process according to Equation (13) above.

[0107] Next, in Step S**111**, the CPU **30** performs an inverse calculation process of inversely calculating the sample value obtained by the process of Step S**108** above based on the parameters of the subtraction unit **13**, and converts the inversely calculated value to the voltage value before being received by the subtraction unit **13**.

[0108] Then, in Step S**112**, the CPU **30** obtains a measurement value (digital value) of the output voltage v_{bat} of the battery **2** and stores the measurement value in the storage unit **36**. By repeating (looping) the processes of Steps S**103** to S**112**, multiple measurement values of the output voltage v_{bat} of the battery **2** are obtained.

[0109] In the case where the termination condition is satisfied, in Step S**114**, the CPU **30** terminates the measurement loop. When the process of Step S**114** is completed, the measurement process shown in FIG. **21** is ended.

[0110] Furthermore, the adjustment process of the subtraction unit **13**, which is executed in Step S**105** of the measurement process of FIG. **21**, will be described. FIG. **22** illustrates a flowchart representing an example of the flow of the subtraction unit adjustment process executed by the microcontroller **16** of the voltage detection device **10**. As shown in FIG. **22**, the subtraction unit adjustment process of the embodiment is similar to the multiplication-and-division unit adjustment process of the first embodiment (see FIG. **13**).

[0111] Specifically, in Step S**500** of FIG. **22**, the CPU **30** measures the output voltage v_{bat} of the battery **2** for a fixed period of time, and obtains and retains the maximum value V_{max} and the minimum value V_{min} of the output voltage v_{bat} as digital values.

[0112] Then, in Step S**502**, the CPU **30** derives the average V_{ave} of the output voltage v_{bat} of the battery **2**. In the embodiment, the CPU **30** derives the average V_{ave} by using Equation (4) as described above to calculate the average of the maximum value V_{max} and the minimum value V_{min} of the output voltage v_{bat}.

[0113] Then, in Step S**504**, the CPU **30** sets the output voltage V_{dac} of the DAC **22**. In the embodiment, the output voltage V_{dac} of the DAC **22** is set to be the same as the average V_{ave} of the output voltage v_{bat} of the battery **2**.

[0114] Then, in Step S**506**, the CPU **30** starts the output of the output voltage V_{dac} from the DAC **22**. When the process of Step S**506** is completed, the subtraction unit adjustment process shown in FIG. **22** is completed. Through the subtraction unit adjustment process, the subtraction amount from the output voltage v_{bat} output from the battery **2** is adjusted in the subtraction unit **13**.

[0115] In the embodiment, the voltage detection device **10** including the subtraction unit **13** and the amplification unit **15** is described as an example of a circuit having two functions, i.e., subtraction and amplification, but the disclosure is not limited to the configuration. For example, the configuration may include a single circuit having two functions, i.e., subtraction and amplification. A specific example in this case includes a differential amplification unit.

[0116] As described above, the voltage detection device **10** of the first and second embodiments is a voltage detection device that measures the output voltage of the battery **2** by using the ADC **20**. The voltage detection device **10** includes the multiplication-and-division unit **12** or the subtraction unit **13**, which functions as a level shift unit that shifts the voltage level of the voltage signal output from the battery **2** to the median of the measurement range of the ADC **20**. The voltage detection device **10** also includes the amplification unit **14** or the amplification unit **15** that amplifies the voltage signal in which the voltage level has been shifted by the multiplication-and-division unit **12** or the subtraction unit **13**. Additionally, the voltage detection device **10** includes the ADC **20** that measures the voltage signal amplified by the amplification unit **14** or the amplification unit **15** and outputs a digital sample signal corresponding to the voltage signal. The voltage detection device **10** also includes the microcontroller **16** containing the CPU **30** that derives the voltage value of the output voltage of the battery **2** based on the sample signal output from the ADC **20**.

[0117] For example, unlike the voltage detection device **10** of the embodiment, in a case where a battery is connected to an ADC and the output voltage v_{bat} of the battery is directly detected by the ADC, if the resolution of the ADC is low, among the changes of the output voltage v_{bat}, for small changes (amplitudes) over a short period of time corresponding to the load connected to the battery may be rounded to a constant digital value and cannot be detected. On the other hand, if the resolution of the ADC is increased to detect small changes (amplitudes), the cost may increase. Additionally, if the measurement range of the ADC is widened to detect large changes over a long period of time, the measurement values of small changes over a short period of time become coarse. Moreover, during the measurement of small changes over a short period of time, only a portion of the measurement range of the ADC is used. Therefore, most of the measurement range remains unused, and the performance cannot be fully utilized. Meanwhile, if the measurement range of the ADC is reduced to detect small changes over a short period of time, the circumstances such as the time of full charge or the time immediately before complete discharge may fall outside the measurement range of the ADC, for example, and large changes over a long period of time may not be detectable.

[0118] Comparatively, the voltage detection device **10** of the first and second embodiments, with the configurations described above, can measure the output voltage of the battery **2** within the measurement range of the ADC **20** regardless of the output voltage of the battery as well as the magnitude of the amplitude. Therefore, it can accurately detect both long-term changes and short-term changes in the output voltage of the battery.

[0119] While the amplification unit **14** of the first embodiment and the amplification unit **15** of the second embodiment are described as a non-inverting amplification unit in the above description, an inverting amplification unit may also be adopted in accordance with the properties of voltage changes. In the case where an inverting amplification unit is adopted, the sample value measured by the ADC **20** from the output of the amplification unit **14** or the amplification unit **15** is an inverted value of the actual output voltage v_{bat} of the battery **2**. Therefore, the output voltage v_{bat} of the battery **2** can be derived by performing calculation that takes into account the inversion of the value.

[0120] Furthermore, while the first embodiment describes adjusting the multiplication-and-division unit **12** by using the output of the DAC **22** and the second embodiment describes adjusting the subtraction unit **13** by using the output of the DAC **22**, the adjustment of the multiplication-and-division unit **12** or the subtraction unit **13** may also be performed by means other than the DAC **22**. As an alternative to the DAC **22**, for example, a means capable of generating an arbitrary voltage can be used.

[0121] In addition, in the first embodiment, a variable resistor other than an analog photocoupler may be used as the variable resistor **106** of the amplification unit **14**. For example, a variable resistor in which the resistance value is controlled by a switch may also be used. In the case where a variable resistor in which the resistance controlled by a switch is used, to control the resistance value, a DAC or a general-purpose input/output (GPIO) may be used as appropriate in place of the PWM **24**, depending on the type of the resistor. In the case of using a DAC for resistance value control, it is necessary to prepare a separate channel from the DAC **22**. Furthermore, in the case where a variable resistor other than an analog photocoupler, the resistor **100** may not be necessary.

[0122] Several appendices are further disclosed in the following in relation to the above embodiments.

Appendix 1

[0123] A voltage detection device, measuring a voltage of a battery by using an analog-to-digital converter (ADC). The voltage detection device includes: a level shift unit, shifting a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC; an amplification unit, amplifying the voltage signal in which the voltage level is shifted by the level shift unit; the ADC, measuring the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and a derivation unit, deriving a voltage value of a voltage of the battery based on the sample signal output from the ADC.

Appendix 2

[0124] In the voltage detection device according to Appendix 1, the level shift unit includes a multiplication-and-division unit performing multiplication or division on the voltage value of the voltage signal output from the battery.

Appendix 3

[0125] In the voltage detection device according to Appendix 1, the level shift unit includes: a subtraction unit, performing subtraction from the voltage value of the voltage signal output from the battery.

Appendix 4

[0126] In the voltage detection device according to Appendix 1, the level shift unit and the amplification unit are formed by one circuit.

Appendix 5

[0127] In the voltage detection device according to Appendix 4, the circuit shifts the voltage level of the voltage signal by performing subtraction from the voltage value of the voltage signal output from the battery.

Appendix 6

[0128] In the voltage detection device according to Appendix 1, an amplification degree of the amplification unit is arranged to be variable.

Appendix 7

[0129] In the voltage detection device according to Appendix 1, an amplification degree of the amplification unit is arranged to be fixed.

Appendix 8

[0130] In a voltage detection method, a processor included in a voltage detection device that measures a voltage of a battery by using an analog-to-digital converter (ADC) is configured to: shift, by using a level shift unit, a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC; amplify, by using an amplification unit, the voltage signal in which the voltage

level is shifted by the level shift unit; measure, by using the ADC, the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and derive a voltage value of a voltage of the battery based on the sample signal output from the ADC.

Appendix 9

[0131] In a voltage detection program, a processor included in a voltage detection device that measures a voltage of a battery by using an analog-to-digital converter (ADC) is arranged to: shift, by using a level shift unit, a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC; amplify, by using an amplification unit, the voltage signal in which the voltage level is shifted by the level shift unit; measure, by using the ADC, the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and derive a voltage value of a voltage of the battery based on the sample signal output from the ADC.

What is claimed is:

1. A voltage detection device, measuring a voltage of a battery by using an analog-to-digital converter (ADC), the voltage detection device comprising:

a level shift unit, shifting a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC;

an amplification unit, amplifying the voltage signal in which the voltage level is shifted by the level shift unit;

the ADC, measuring the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and

a derivation unit, deriving a voltage value of a voltage of the battery based on the sample signal output from the ADC.

2. The voltage detection device as claimed in claim **1**, wherein the level shift unit comprises a multiplication-and-division unit, performing multiplication or division on the voltage value of the voltage signal output from the battery.

3. The voltage detection device as claimed in claim **1**, wherein the level shift unit comprises:

a subtraction unit, performing subtraction from the voltage value of the voltage signal output from the battery.

4. The voltage detection device as claimed in claim **1**, wherein the level shift unit and the amplification unit are formed by one circuit.

5. The voltage detection device as claimed in claim **4**, wherein the circuit shifts the voltage level of the voltage signal by performing subtraction from the voltage value of the voltage signal output from the battery.

6. The voltage detection device as claimed in claim **1**, wherein an amplification degree of the amplification unit is arranged to be variable.

7. The voltage detection device as claimed in claim **1**, wherein an amplification degree of the amplification unit is arranged to be fixed.

8. A voltage detection method, wherein a processor comprised in a voltage detection device that measures a voltage of a battery by using an analog-to-digital converter (ADC) is configured to:

shift, by using a level shift unit, a voltage level of a voltage signal output from the battery to a median of a measurement range of the ADC;

amplify, by using an amplification unit, the voltage signal in which the voltage level is shifted by the level shift unit;

measure, by using the ADC, the voltage signal amplified by the amplification unit, and outputting a digital sample signal in accordance with the voltage signal; and

derive a voltage value of a voltage of the battery based on the sample signal output from the ADC.

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