Technical Note

Switch Mainframe SW1001/SW1002 Multiplexer Module SW9001/SW9002

Tatsuya Sato

DB Unit, Innovation Center

***Abstract*—In measuring battery impedance, the error component varies by channel when switching among multiple channels (with a multiplexer). Hioki studied the wiring design of such devices and developed a new switch characterized by smaller error components. This paper introduces the resulting products' features, architecture, and characteristics.**

I. Introduction

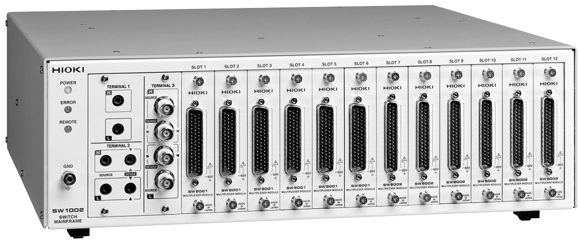
In recent years, demand for batteries has been growing, particularly for use in applications such as smartphones, notebook computers, and hybrid electric vehicles (HEVs) and electric vehicles (EVs). Inspection processes at battery manufacturing plants typically use the AC impedance method to measure batteries' internal resistance. To maximize productivity, the most common approach is to switch among multiple batteries (using a multiplexer). When doing so, a large error component can be introduced into measured values due to the effects of factors such as switch eddy current. To address this issue, Hioki leveraged the technology it has accumulated as a manufacturer of measuring instruments to develop the Switch Mainframe SW1001/SW1002 and the Multiplexer Module SW9001/SW9002, which allow combined accuracy with connected instruments to be guaranteed.

II. Overview

In battery measurement, the AC impedance method is often used to measure internal resistance. When doing so, measurement error can occur if the probe's cable layout or positioning is not taken into consideration. This issue is particularly pronounced for switches with a large number of channels, which are prone to introduce error due to the fact that each channel's measurement path is branched. Consequently, such setups yield measurement results with error components that differ for each channel.

The wiring patterns on the SW1001/SW1002's circuit boards have been designed so as not to introduce error into measurement signals, allowing combined accuracy to be guaranteed when used in combination with supported measuring instruments. Hioki offers the following instruments (connection methods) and measurement channel counts:

Appearance of the SW1001, SW9001, and SW9002 (left to right).



Appearance of the SW1002.

- Switch Mainframe (used to house and control modules)
  SW1001: 2-wire, up to 66 channels (3 slots)
  SW1002: 2-wire, up to 264 channels (12 slots)
- Multiplexer Module
  SW9001: 2-wire (22 channels), 4-wire (11 channels)
  SW9001: 2-wire (6 channels), 4-terminal-pair (6 channels)

III. Functionality and Features

A. Guaranteed Accuracy When Used in Combination With Impedance Measuring Instruments

An AC signal is applied to the battery, and the signal that results from the battery's impedance is detected to measure its internal resistance. An offset occurs due to the following principle (Fig. 1):

1. The applied AC signal generates magnetic flux.
2. The magnetic flux generates an eddy current in metal near the probes, and the eddy current in turn generates magnetic flux.
3. The magnetic flux passes through the detection loop, causing an offset.

Since the path traveled by the measurement signal varies for each channel, the magnitude of the offset also varies, with the result that errors occur between channels. To resolve this issue, Hioki has arranged opposing high and low AC signal wiring patterns inside the switch to cancel out the magnetic flux and reduce the resulting offsets (Fig. 2).

Because the magnetic flux passing through loops in wiring patterns on the detection signal side also causes an offset, wiring has been designed to minimize loop area. Furthermore, measurement current wiring and detection signal wiring have been separated in order to the reduce the effects of eddy currents (Fig. 3).

These innovations make it possible to reduce the effects on measured values so that combined accuracy of the Switch Mainframe and connected measuring instruments can be guaranteed.

B. Reduced Pattern Resistance

Instruments used to measure battery impedance are required to have low wiring pattern resistance on the order of several ohms or less. Hioki has kept this resistance low by using wider wiring patterns on the products' printed circuit boards and by increasing the thickness of copper foil.

C. Fuse Protection Against Battery Short-Circuits

Mechanical relays are used to switch between channels in order to reduce measurement error. Such relays pose the risk of multiple channels being closed at the same time due to factors such as part failure and contact adhesion. In the event that multiple channels were closed at the same time while measuring individual battery cells connected in series on a battery pack, the serially connected batteries could be shorted out.

Hioki protects batteries against such short-circuits by adding a fuse to each channel's inputs.

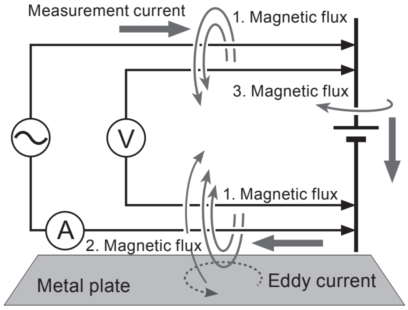


Fig. 1. Offsets from eddy currents.

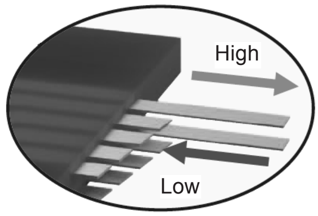


Fig. 2. Cancellation of magnetic flux.

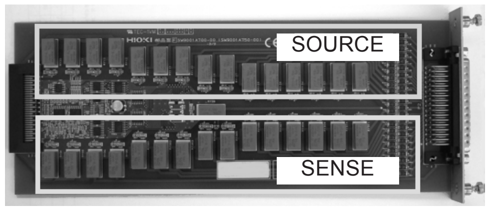


Fig. 3. Sense/source separation.

D. Support for Dual Measuring Instruments

Battery measurement includes impedance, battery voltage, and potential (insulation) between electrodes and the battery's enclosure. Up to two instruments can be connected to the Switch Mainframe, which can switch between them to measure the battery connected to each channel.

E. Terminals That Can Be Connected As-Is to Instruments

The Switch Mainframes provide the terminals listed below for connecting instruments. Since instruments and Switch Mainframes use the same terminal type, connections are simple and intuitive.

- TERMINAL 1: 2-wire banana terminal (2 terminals)
- TERMINAL 2: 4-wire banana terminal (4 terminals)
- TERMINAL 3: 4-terminal pair BNC connector

IV. Architecture

A. Switch Mainframe SW1001/SW1002

1) Overview: Fig. 4 provides an overall block diagram for the system. Switches consist of the Switch Mainframe and Multiplexer Modules ("modules"). The Switch Mainframe has four analog buses that connect measurement signals from modules to the instrument terminals (TERMINALs

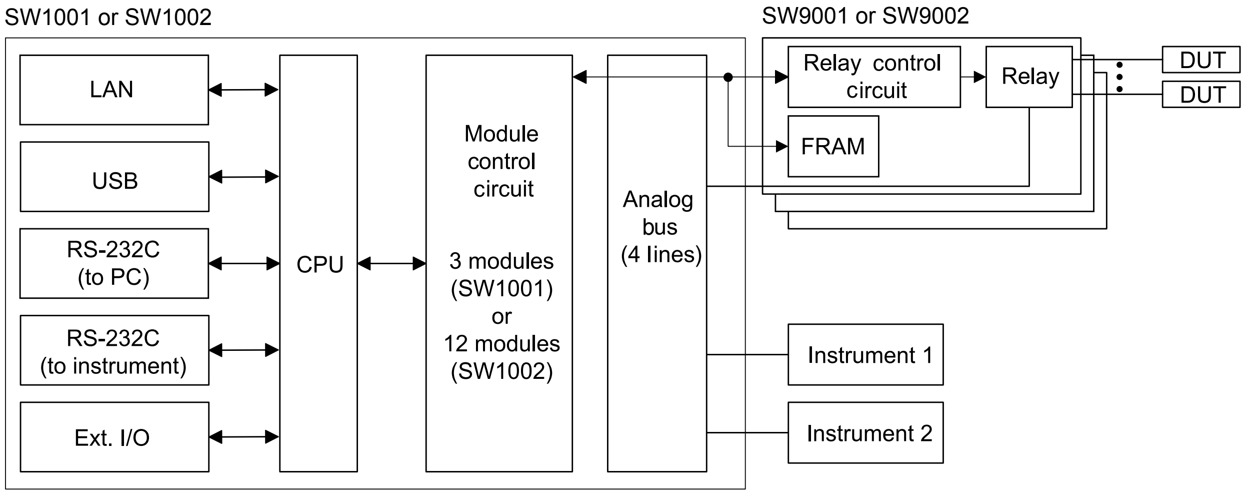


Fig. 4. Block diagram (overall system).

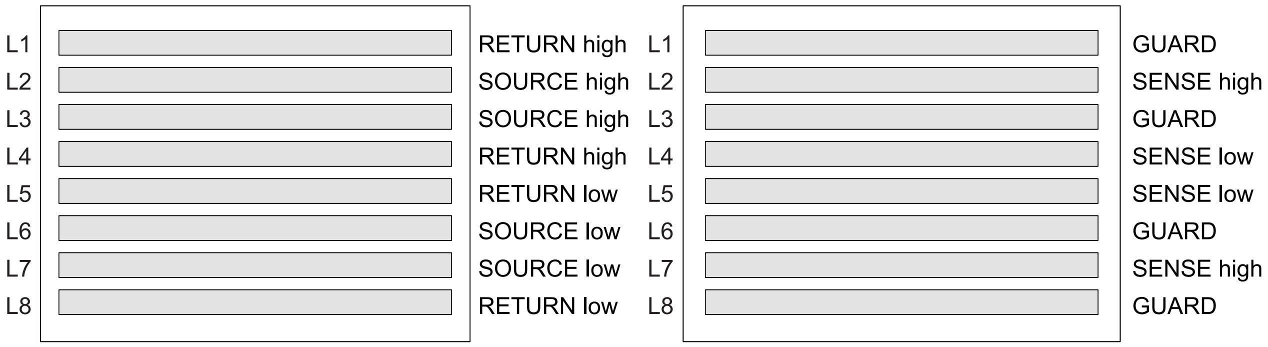


Fig. 5. Analog bus placement on circuit board.

1 through 3). Switching between channels is controlled by commands from a computer (PC) via a communications interface.

Modules use relays to switch signals from multiple channels and connect them to the Switch Mainframe's analog buses. Relays connected to the analog buses can switch among 2-wire, 4-wire, and 4-terminal-pair connection methods.

2) Analog buses (Fig. 5)

a) Bus architecture that supports 2-wire, 4-wire, and 4-terminal-pair connections: The SW1001/SW1002's internal buses support all connection architectures of Hioki products such as the following so that they can be connected:

- 2-wire
  Precision DC Voltmeter DM7275/DM7276
- 4-wire
  Battery HiTester BT3562/BT3563/3561
- 4-terminal-pair
  Battery Impedance Meter BT4560
  Chemical Impedance Analyzer IM3590

Additionally, current buses (SOURCE/RETURN) and the voltage bus (SENSE) have been separated to reduce the effect on measurement current detection signals, and an 8-layer board has been used to lower the resistance of bus lines.

b) Separate placement of analog and digital terminals: Analog wiring between the instrument and device under test has been placed on the front panel, while control wiring has been placed on the rear panel in order to separate analog signals from CPU digital circuits. Consequently, analog signals are not affected by digital wiring.

3) Control circuits

a) SW1001/SW1002 shared design: Fig. 4 provides an overall block diagram for the system, including modules.

By limiting the difference between the SW1001 and SW1002 to individual modules' circuits, Hioki was able to use the same circuit boards for the CPU's peripheral circuitry and control circuitry. Additionally, use of the same firmware keeps control methods identical.

b) Exclusive channel control: In a system that uses a multiplexer to measure batteries, closing multiple channels for even an instant could short-circuit the battery. Consequently, it is necessary to exercise caution with regard to factors such as channel settings and the timing at which, and order in which, switches are opened and closed.

To the extent general-purpose multiplexers offer a high degree of freedom, they require designers to exercise care with regard to safety when building systems around them.

The SW1001/SW1002 uses a "break-before-make" control philosophy to ensure that multiple channels are not closed at the same time, allowing safe, simple battery measurement.

4) Software

a) Shared frameworks: The SW1001/SW1002 uses a μITRON real-time operating system (OS), and Hioki has implemented frameworks that can be shared by other products on top of that OS.

Settings, communications, and internal system communications have been implemented as frameworks, and the SW1001/SW1002's control functionality has been implemented using those frameworks.

b) Simultaneous acceptance of commands from communication interfaces: The SW1001/SW1002 can be controlled using multiple interfaces (LAN, USB, and RS-232C). Most legacy products with multiple interfaces required that the user set which interface would be used in advance.

Since the SW1001/SW1002 executes only one control command at a time, conflicts between multiple interfaces are eliminated. Consequently, the product can be controlled without attention to which interface is enabled and without the need to switch among multiple interfaces.

c) Command transfers: Since the SW1001/SW1002 must be used with at least one measuring instrument, it is necessary for the user to implement communications and control with multiple devices such as a PC and programmable logic controller (PLC). The process of orchestrating communications with multiple devices is prone to become complex.

To alleviate this issue, Hioki equipped the SW1001/SW1002 with two RS-232C ports to facilitate communications with measuring instruments and provided functionality to allow command and measurement data to be transferred to instruments via the SW1001/SW1002 without connecting them to a PC. Additionally, since measurement commands are sent to the instruments only after the SW1001/SW1002's relay contacts have been closed, there is no need for the user to allow time for the relay contacts to close.

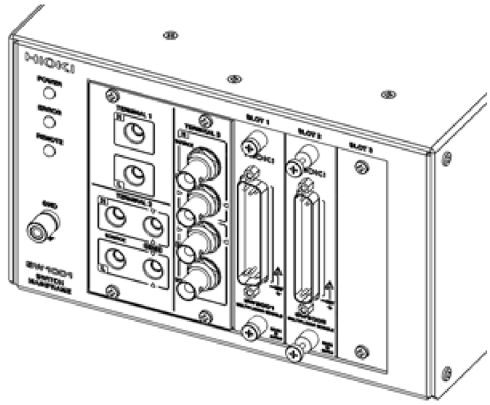


Fig. 6. Connection terminals and set screws on front of SW1001.

This functionality significantly reduces user workload since the control device need only communicate with one SW1001/SW1002.

5) Construction (Fig. 6): Module slots and instrument connection terminals have been located on the front of the product to allow basic control to be accomplished more conveniently. Operation can be checked via LEDs on the front of the device, ensuring both ease of operation and visibility. Additionally, since set screws are captive and can serve as knobs, which eliminate the concern or dropping the screws, uses can remove modules from the SW1001/SW1002 without the use of dedicated tools. These design features improve operability for the user.

B. Multiplexer Module SW9001

1) Overview: The SW9001 is a module capable of switching among 22 channels (2-wire) or 11 channels (4-wire). It is ideal for multichannel measurement using the DM7276 in 2-wire voltage measurement applications and for use with the 4-wire BT3562/3561.

2) Switching circuits: The module's switching circuits use relays.

Since the module is designed for use in battery testing, relay adhesion or delays in relay operation could cause a short circuit between the terminals of the battery under test. To prevent this hazard, each channel incorporates a built-in fuse.

Switching of the internal relays allows measurement of 22 channels if using 2-wire connections (twice as many as with 4-wire connections).

C. Multiplexer Module SW9002

1) Overview: The SW9002 is a module capable of switching among 6 channels (2-wire or 4-terminal-pair).

It is ideal for use with the 4-terminal-pair BT4560 or IM3590, or with the DM7276 in 2-wire voltage measurement applications.

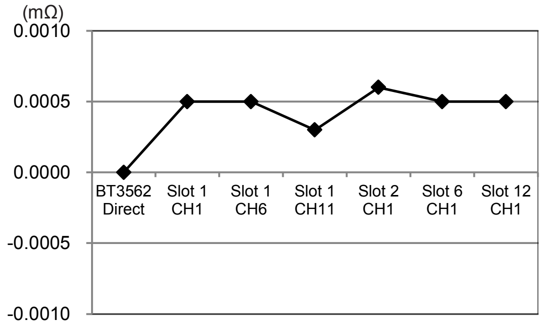


Fig. 7. Example combination characteristics: BT3562.

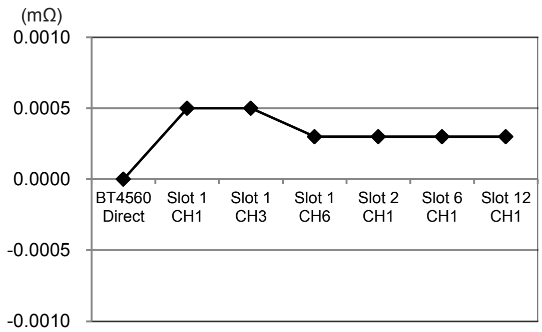


Fig. 8. Example combination characteristics: BT4560 (R).

2) Switching circuits: The module's switching circuits use relays.

Since the SW9002 supports 4-terminal-pair connections, it incorporates relays for switching among both source lines and return lines on the current side.

To cancel out magnetic flux from current, source lines and return lines have been placed adjacently in an opposing orientation so that the current they carry flows in opposite directions.

V. Characteristics

A. Multiplexer Module SW9001 Characteristics

1) Characteristics when used in combination with the BT3562: Fig. 7 provides an example of combination characteristics for the SW9001 and BT3562.

The difference between measured values when measuring a resistance of 0 mΩ directly with the BT3562 without using the switch and via the switch is 0.001 mΩ or less.

B. Multiplexer Module SW9002 Characteristics

1) Characteristics when used in combination with the BT4560: Figs. 8 and 9 provide examples of combination characteristics for the SW9002 and BT4560 (with a measurement frequency of 1000 Hz).

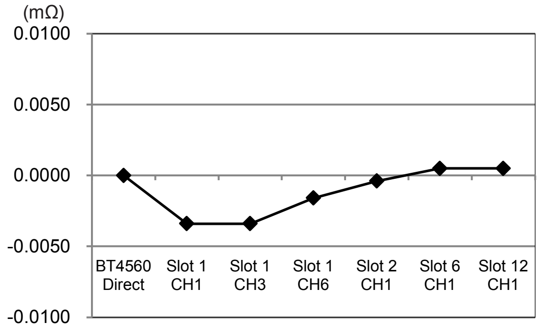


Fig. 9. Example combination characteristics: BT4560 (X).

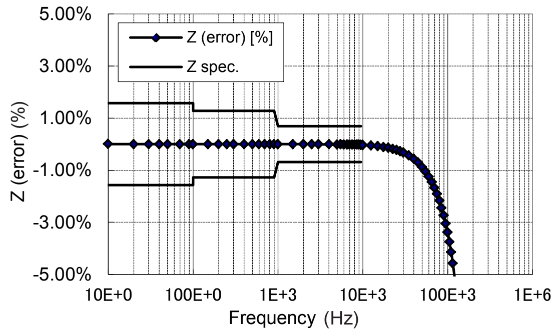


Fig. 10. Example combination characteristics: IM3590 (Z).

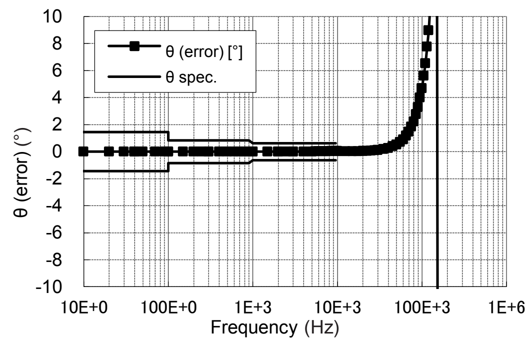


Fig. 11. Example combination characteristics: IM3590 (θ).

The difference between measured values (R) when measuring a resistance of 0 mΩ directly with the BT4560 without using the switch and via the switch is 0.001 mΩ or less. *R* indicates the equivalent series resistance, while *X* indicates the reactance.

2) Characteristics when used in combination with the IM3590: Figs. 10 and 11 provide examples of combination characteristics for the SW9002 and IM3590 (difference in 10 kΩ measured values from the IM3590/switch and IM3590 alone). The newly developed switches are designed primarily for use with battery testers, and they feature wider patterns and higher capacitance between signal lines and relative to ground in order to lower wire pattern resistance. Consequently, error is greater in the domain characterized by frequency values of 10 kHz or greater and impedance values of 10 kΩ or greater.

VI. PC Application

A. Overview

Hioki developed a PC application that makes it easy to measure multiple channels in order to maximize user convenience.

B. Cole-Cole Plot

The application makes it easy to measure Cole-Cole plot characteristics for multiple batteries when used with an instrument such as the BT4560 (Fig. 12).

C. OCV Measurement Function

The application provides a mode for logging open-circuit voltage (OCV) measurements (Fig. 13).

In addition to OCV measured values, it offers functionality for calculating values such as variation from initial voltage values and voltage drop rates (mV/day), making it easy to record batteries' self-discharge characteristics.

VII. Conclusion

The SW1001/SW1002 and SW9001/SW9002 allow multiple batteries to be measured easily and accurately in battery R&D and mass-production inspection settings. Users will find themselves freed from past challenges associated with such applications so that they can better focus on more important job responsibilities. Hioki expects the products to contribute to the development of the battery industry in the future.

Akira Yanagisawa[1], Kenji Nagai[1], Takuji Kobayashi[1], Shunsuke Yokosawa[1], Hiroshi Yamazaki[2]

Fig. 12. PC application (Cole-Cole plot).

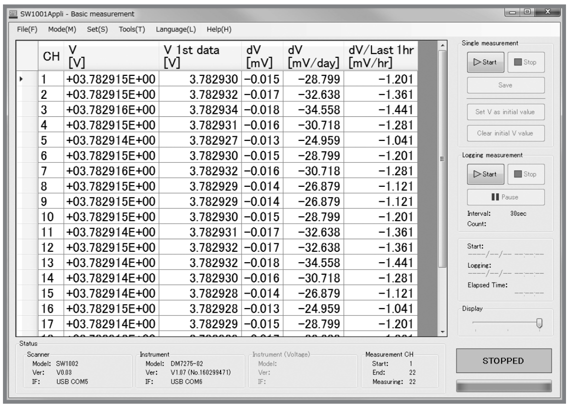


Fig. 13. PC application (OCV measurement function).

---

[1] DB Unit, Innovation Center
[2] After Service Division, Manufacturing Department