# Insulation Tester ST5520

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*Abstract*—**The Insulation Tester ST5520 is an insulation resistance tester that delivers test times as fast as 50 ms with contact check functionality and user-configured test voltages. It was developed as the successor to the Digital MΩ HiTester 3154, Hioki's legacy model, based on the concept of providing fast and exhaustive insulation resistance measurement. This paper describes the ST5520's features and architecture.**

## I. INTRODUCTION

In insulation resistance testing, the insulation performance of the device under test is evaluated by applying a DC voltage and calculating the device's resistance value. A wide range of objects, including components such as connectors, relays, and transformers as well as lithium-ion batteries used in next-generation energy applications, are tested in this manner to evaluate their safety. As manufacturers work to lower the costs of these products, insulation resistance testing is subject to an extremely high standard of performance in terms of cycle time and test quality. Hioki developed the Insulation Tester ST5520 to satisfy the demands of high-speed, high-quality testing.

## II. OVERVIEW AND DESIGN CONCEPT

After visiting numerous end-users, Hioki learned that they considered the test time to extend beyond the amount of time required to prepare the instrument for testing so that it includes the time needed for the test voltage to fall to a safe level. Fig. 1 provides an overview of this definition of test time. In designing the ST5520, Hioki sought to deliver test times as short as 50 ms while simultaneously shortening charge and discharge times, which together with setup time determine how long testing will take.

During insulation resistance testing, which involves applying a DC voltage to the device under test, a period of time known as the charge time is necessary in order for the voltage to rise to the set level if the device under test includes a capacitance component. Furthermore, a period of time known as the discharge time is necessary after testing in order for the test voltage to fall. The ST5520 has been designed to give the end-user a concrete sense of speed by shortening both the charge and discharge times. The following sections provide more information about the instrument's functionality and features.

Appearance of the ST5520

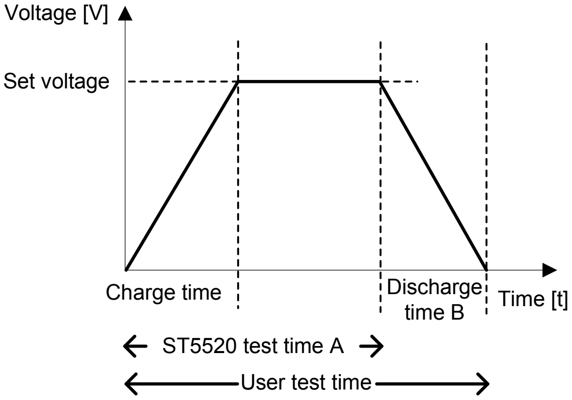

Fig. 1. Overview of Test Time

## III. FUNCTIONS AND FEATURES

### A. Fast Measurement

The following describes functionality implemented by the ST5520 in order to deliver fast measurement:

#### 1) Test times as fast as 50 ms

The ST5520's most remarkable feature is its achievement of test times as fast as 50 ms. This time can be achieved with the maximum sampling speed of 30 ms and the FAST measurement speed setting. (See "A" in Fig. 1.)

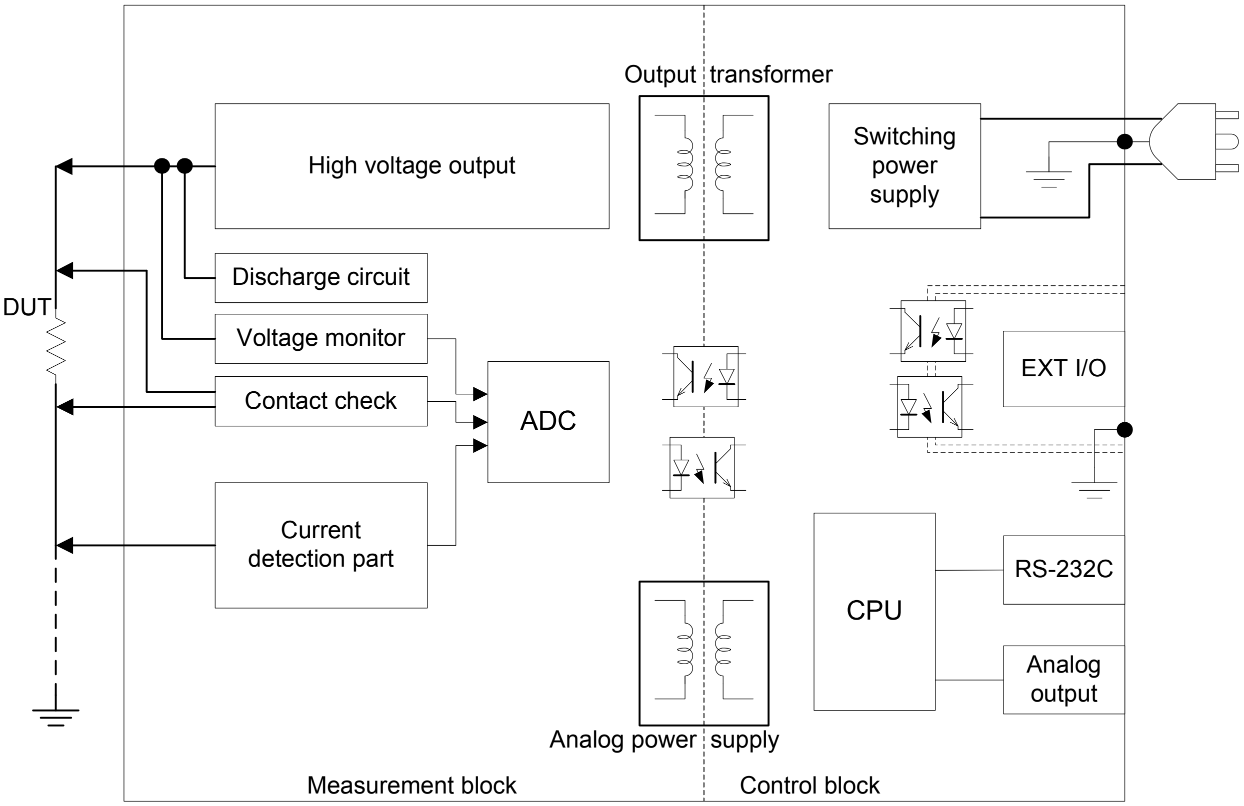

Fig. 2. Block Diagram

*2) High-speed automatic discharge function*

Any charge remaining on the device under test could result in electric shock or damage to the device. The ST5520 achieves dramatically shorter discharge times by improving on the discharge method used by the Digital MΩ HiTester 3154, Hioki's legacy model. (See "B" in Fig. 1.)

### *B. Improved Test Quality*

*1) Contact check function*

Faulty contact or a wiring break in the measurement cable during insulation resistance testing will cause the test to yield higher resistance values, raising the risk that defective devices will be incorrectly judged to be non-defective. To prevent this type of erroneous judgment, the ST5520 incorporates a contact check function that checks for faulty contact and wiring breaks at an interval of 100 ms from the start of testing until judgment results are output. In the event that faulty contact or a wiring break is detected, testing is halted.

*2) Short check function*

Some devices under test may exhibit minor shorts caused by metal filings or other foreign material, a phenomenon known as a micro-short. In some cases, a micro-short can develop into a wring break when a high voltage is applied, eliminating the shorted state and yielding a test result that incorrectly suggests the device in question is non-defective. To avoid this possibility, the ST5520 incorporates a short check function that checks for micro-shorts by applying a lower voltage (2 V to 5 V) than the test voltage.

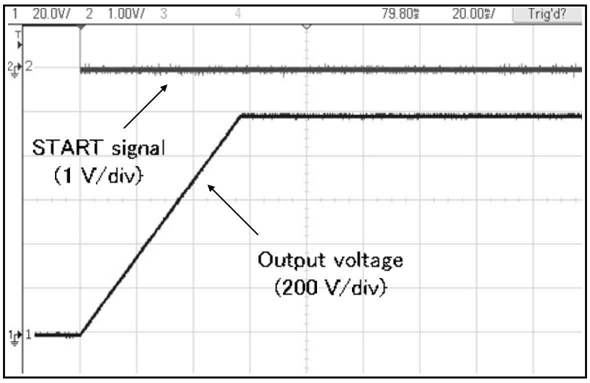

Fig. 3. Output Voltage Waveform (Horizontal axis: 20 ms/div.)

*3) User-configured test voltage (25 V to 1,000 V)*

Currently, because no standard defines a specific test voltage for insulation resistance testing of devices such as lithium-ion batteries, operators are free to set their own test voltages. Consequently, the ST5520 allows end-users to set the test voltage as desired.

## IV. HARDWARE ARCHITECTURE

Fig. 2 provides an overall block diagram for the ST5520, which consists of a control block that is responsible for the user interface as well as isolated measurement and EXT. I/O blocks.

### A. *Voltage and Current Sources*

The output voltage can be set from 25 V to 1,000 V with a resolution of 1 V. In addition, an output current of up to 2 mA can be used in all voltage ranges.

The output voltage may exhibit overshoot when testing a capacitive load. Since an overshoot state causes a voltage in excess of the set voltage to be applied, this phenomenon could damage the device under test. The ST5520 has been designed to limit overshoot. As an example, Fig. 3 provides the output voltage waveform when generating a voltage of 1 kV for a capacitive load of 0.1 μF.

Test times for resistance loads are 1 ms to 25 ms shorter (25 V to 1,000 V). Figs. 4 and 5 provide output voltage ripple waveforms for no-load conditions. Output voltage ripple exhibits amplitude that is one-half that of the legacy model and frequency that is about 27 times greater. Although output voltage ripple affects current measurement as a noise source, Hioki was able to use a smaller current detection block filter, which serves to eliminate noise, by increasing the frequency of the output voltage ripple.

### B. *Discharge Circuit Block*

The legacy model used constant-resistance discharge with a discharge resistance of 12 MΩ. With a capacitive load, the discharge time is determined by the discharge resistance and the load capacitance's time constant. Consequently, high load capacitance values resulted in longer discharge times.

The ST5520 shortens discharge times by using constant-current discharge at about 10 mA.

The amount of time required for discharge to complete can be calculated using (1) and (2) below:

3154 (Hioki's legacy model):

$$t = C \cdot R \cdot \ln\left(\frac{V_0}{V_1}\right) \tag{1}$$

ST5520:

$$t = \frac{\left(C \cdot \left(V_0 - V_1\right)\right)}{I} \tag{2}$$

$C$: Load capacitance
$R$: Discharge resistance
$V_0$: Charged voltage
$V_1$: Post-discharge voltage
$I$: Discharge current

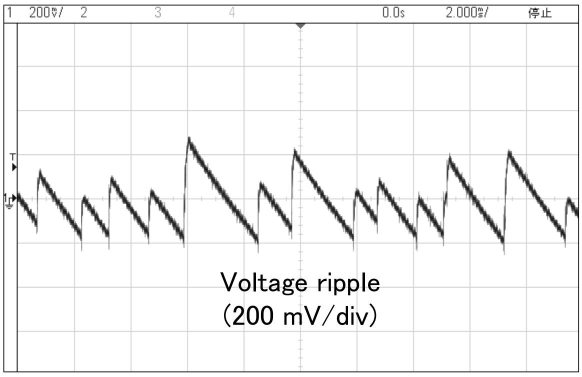

Fig. 4. Legacy Model Ripple Waveform (Horizontal axis: 2 ms/div.)

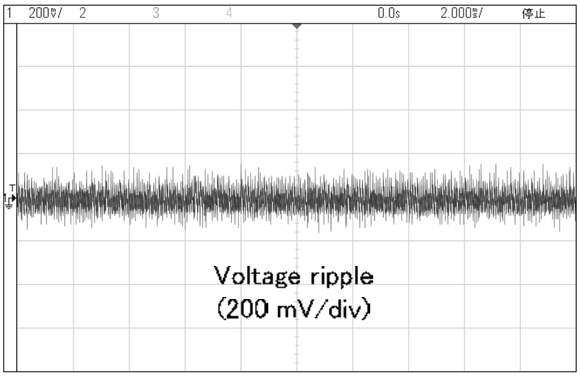

Fig. 5. ST5520 Ripple Waveform (Horizontal axis: 2 ms/div.)

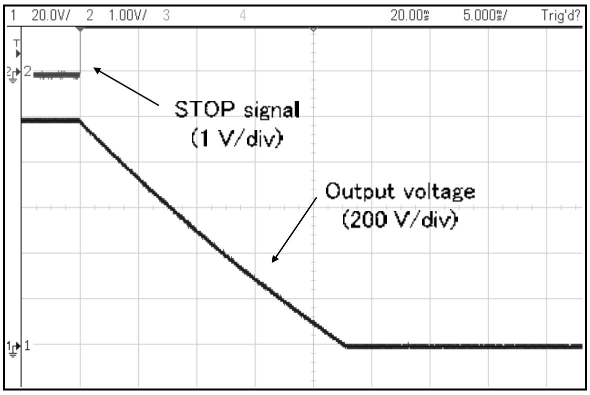

Fig. 6. Discharge Waveform (Horizontal axis: 5 ms/div.)

As an example, whereas it takes about 5.5 sec. to discharge a capacitive load of 0.1 μF from 100 V to 1 V when using 12 MΩ constant-resistance discharge, that process takes just 0.99 ms when using constant-current discharge.

Test times can be reduced by shortening the amount of time required for discharge.

Fig. 6 provides the discharge waveform a 1,000 V charge of a 0.3 μF capacitive load, illustrating how discharge can be completed in about 25 ms.

TABLE I. REPEATABILITY (25 V OUTPUT VOLTAGE, FAST MEASUREMENT SPEED SETTING)

| **Resistance range** | **2000 MΩ range** | **200 MΩ range** | **20 MΩ range** | **2 MΩ range** |
|---|---|---|---|---|
| **Resistance load** | **1000 MΩ** | **100 MΩ** | **10 MΩ** | **1 MΩ** |
| 0.001 μF | — | ±0.2% | ±0.2% | ±0.2% |
| 0.01 μF | — | ±0.6% | ±0.1% | ±0.2% |
| 0.05 μF | — | ±2.6% | ±0.3% | ±0.2% |
| 0.1 μF | — | ±4.9% | ±0.5% | ±0.2% |

TABLE II. REPEATABILITY (100 V OUTPUT VOLTAGE, FAST MEASUREMENT SPEED SETTING)

| **Resistance range** | **2000 MΩ range** | **200 MΩ range** | **20 MΩ range** | **2 MΩ range** |
|---|---|---|---|---|
| **Resistance load** | **1000 MΩ** | **100 MΩ** | **10 MΩ** | **1 MΩ** |
| 0.001 μF | ±0.2% | ±0.2% | ±0.2% | ±0.2% |
| 0.01 μF | ±2.0% | ±0.3% | ±0.2% | ±0.2% |
| 0.05 μF | ±6.7% | ±0.7% | ±0.3% | ±0.2% |
| 0.1 μF | ±15.9% | ±2.0% | ±0.5% | ±0.2% |

TABLE III. REPEATABILITY (500 V OUTPUT VOLTAGE, FAST MEASUREMENT SPEED SETTING)

| **Resistance range** | **4000 MΩ range** | **200 MΩ range** | **20 MΩ range** | **2 MΩ range** |
|---|---|---|---|---|
| **Resistance load** | **2000 MΩ** | **100 MΩ** | **10 MΩ** | **1 MΩ** |
| 0.001 μF | ±0.2% | ±0.2% | ±0.2% | ±0.2% |
| 0.01 μF | ±0.4% | ±0.2% | ±0.2% | ±0.2% |
| 0.05 μF | ±2.6% | ±0.3% | ±0.2% | ±0.2% |
| 0.1 μF | ±7.2% | ±0.6% | ±0.2% | ±0.2% |

### C. *Current Detection Block*

Since the current detection block detects minuscule currents as low as 50 nA, filter constants have been determined so as to protect the block from the effects of power supply and other noise.

In addition, sampling is performed in synchronization with the power supply frequency so that the block is protected from the effects of the frequency, and averaging processing is performed by the A/D converter to limit variability to about 50 dB.

TABLEs I through III list repeatability values when measuring a sample consisting of a resistor and capacitor connected in parallel. The percentage values indicate the amount of variability in 100 measurements made after charging of the capacitor is complete.

## V. CONTACT CHECK FUNCTION

### A. *Method*

The ST5520’s contact check function uses a 4-terminal method. Faulty contact is detected by placing four measurement leads in contact with the device under test, two on the voltage application side (high) and two on the current measurement side (low). The applied voltage is detected on the high side, while a floating power supply is applied and the current detected on the low side. Fig. 7 illustrates the principles on which this approach is based.

### B. *High-side Judgment Method*

When the high-side contact resistance (the contact resistance of the two low-side probes) is 0 **Ω**, the reading of the output voltmeter ($V_1$) is equal to the reading of the contact check voltmeter ($V_2$) (see [3] below).

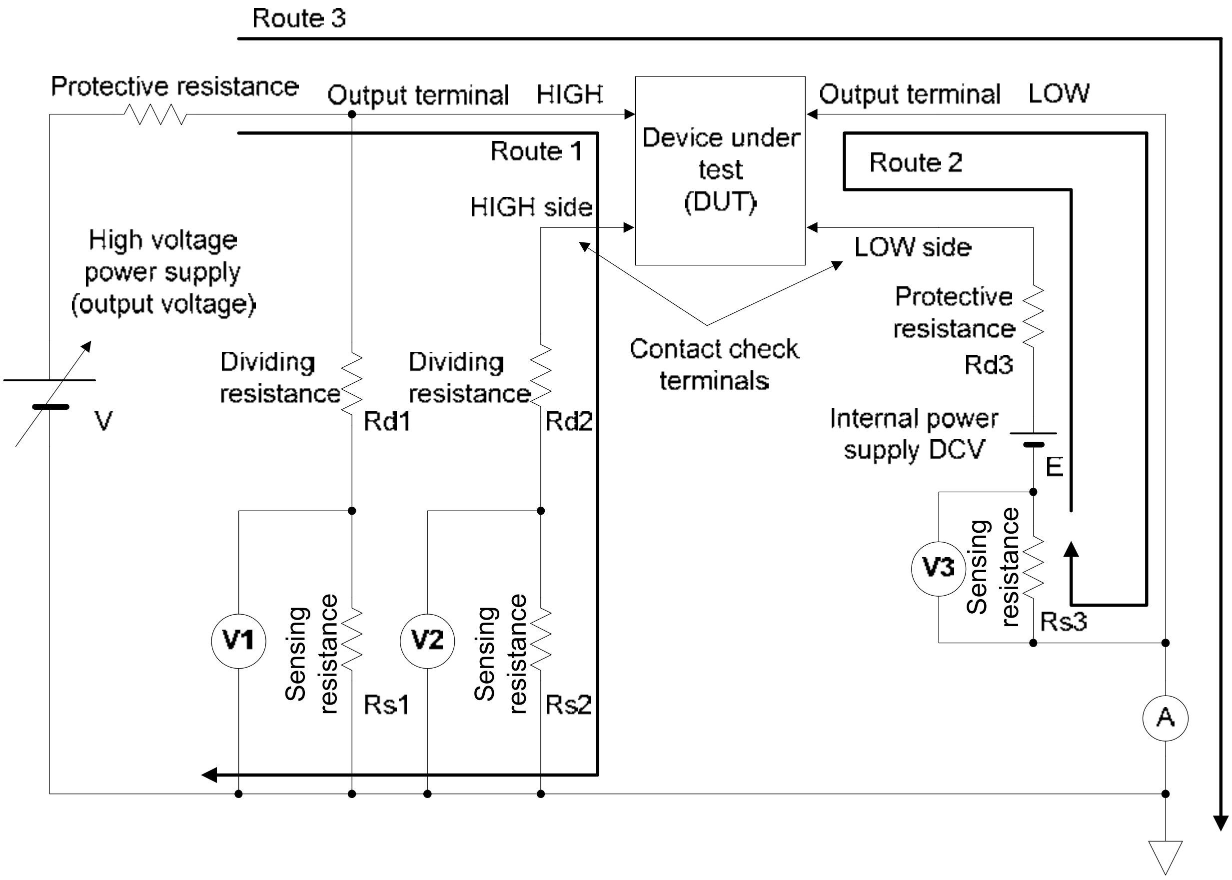

Fig. 7. Contact Check Principles

$$V_2 = V_1 = \frac{V \cdot Rs}{(0 + Rd + Rs)} \tag{3}$$

$V$: Output voltage
$Rs$: Sensing resistance
$Rd$: Dividing resistance

If the high-side contact resistance is $RH$, $V_2$ will be less than $V_1$ (i.e., the result of [5] will be less than the result of [4]).

$$V_1 = \frac{V \cdot Rs1}{(0 + Rd1 + Rs1)} \tag{4}$$

$$V_2 = \frac{V \cdot Rs2}{(RH + Rd2 + Rs2)} \tag{5}$$

The ST5520 determines that faulty contact is occurring if the $V_2$ voltage is 97% of the $V_1$ voltage or less. However, for ranges other than the 2 MΩ range when the current range is being held, the “Under.F” display (which indicates that the current value has exceeded the measurement upper limit) is considered to indicate good contact.

### C. Low-side Judgment Method

If the low-side contact resistance (the contact resistance of the two low-side probes) is 0 Ω, the low-side voltmeter reading is given by (6).

$$V_3 = \frac{E \cdot Rs3}{(0 + Rd3 + Rs3)} \tag{6}$$

$E$: Internal power supply
$Rs3$: Sensing resistance
$Rd3$: Protective resistance

If the low-side contact resistance is $RL$, the result of (7) will be less than the result of (6).

$$V_3 = \frac{E \cdot Rs3}{(RL + Rd3 + Rs3)} \tag{7}$$

The ST5520 calculates the value of $RL$ using (7) and treats a value of about 10 kΩ or greater as indicating faulty contact. However, a current of 0.5 mA or greater flowing to the device under test in the 2 MΩ range is considered to indicate good contact.

### *D. Display of Judgment Results and EXT. I/O Output*

Judgment results are displayed continuously every 100 ms during testing, with “ContHi” indicating detection of faulty contact on the high side, “ContLo” indicating detection of faulty contact on the low side, and “ContHL” indicating detection of faulty contact on both the high and low sides. In addition, an ERR signal is output from the EXT. I/O terminal on the rear of the instrument for all judgment results, and testing is stopped.

## VI. SHORT CHECK FUNCTION

### *A. Method*

After the start of the test but before the set voltage (25 V to 1,000 V) is applied, a low voltage of 2 V to 4 V is applied and the current flowing to the device under test measured. The instrument calculates the resistance value and treats a result of about 100 kΩ or less as indicating a short. When a short is determined to have occurred, the instrument displays the message “Short” to that effect, outputs an ERR signal from EXT. I/O, and halts the test without applying the set voltage. The judgment process can be set from 0.010 to 1.000 sec. (in manual mode).

Since a high voltage is not applied if a short is determined to have occurred, there will be little damage to the device under test, making it easier to perform a failure analysis. Fig. 8 provides a timing chart.

### *B. Judgment Time*

Since insulation test targets generally include capacitance in parallel with insulation resistance, a charge current will flow immediately after a voltage is applied, even when that voltage is low. Although this charge current may be mistaken for a short current if the judgment time is not set properly, the ST5520 provides an auto mode that can be used to investigate appropriate judgment times. When using auto mode, the instrument will display how many seconds it takes for charging to complete and the resistance to rise to about 100 kΩ or higher. Judgment can be performed using the shortest possible time by setting the judgment time in manual mode to the value obtained by adding a bit of cushion to the maximum time displayed after testing several devices in auto mode.

For reference, TABLE IV indicates judgment times when testing a capacitor as the device under test.

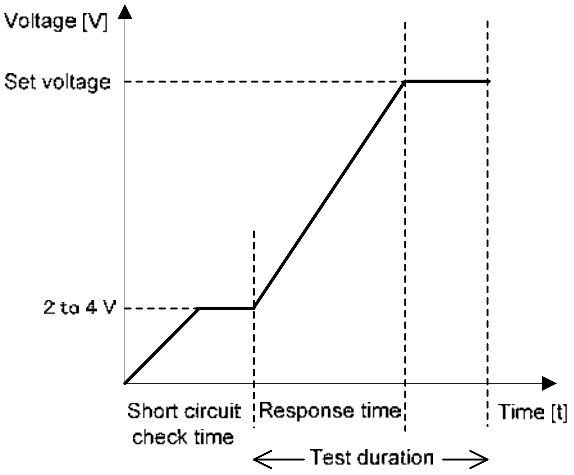

Fig. 8. Short Check Timing Chart

TABLE IV. CAPACITOR SHORT CHECK TIMES (REFERENCE)

| **Capacitance** | 0.01 μF | 0.1 μF | 1 μF |
|---|---|---|---|
| **Judgment time** | 0.020 s | 0.030 s | 0.040 s |

## VII. CONCLUSION

The ST5520 is designed to deliver high-speed performance, including in terms of metrics other than setup time, based on the concept of providing fast and exhaustive insulation resistance measurement. Hioki is confident that the instrument will prove valuable not only on production lines, where fast cycle times are required, but also in applications requiring high-quality testing.

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