

Earth Tester FT6031

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Abstract—The Earth Tester FT6031 is an instrument for measuring the resistance between a grounding electrode and the ground into which it has been driven. It has been designed to dramatically reduce the amount of time needed to perform measurement, including setup and cleanup work. The instrument also features a dustproof and waterproof IP67 enclosure to allow it to be used in harsh, outdoor environments. This paper introduces the product's features.

I. INTRODUCTION

Grounding generally refers to the process of connecting electrical equipment to the ground. Today, a broad range of devices that use electricity are grounded in order to prevent electric shock and short-circuit accidents as well as to protect equipment from abnormal voltages caused by lightning and other phenomena^[1].

Detailed provisions concerning electrical safety are laid out in the *Interpretation of Technical Standards for Electrical Equipment*, which provides specific information about the technical requirements imposed by the ministerial ordinances that set forth technical standards for electrical equipment. According to the interpretation above, published by Japan's Ministry of Economy, Trade and Industry, ground installations are categorized into four classes (A through D), each of which has its own grounding resistance value.

A method known as three-pole measurement has conventionally been used to measure grounding resistance. In this method, two auxiliary earthing rods are used in addition to the grounding electrode being measured (indicated by the letter E), one to carry current (indicated by the letter H) and the other to measure voltage (indicated by the letter S). However, since these auxiliary earthing rods use simple grounding, the grounding resistance tends to increase. In particular, the resistance values of the auxiliary earthing rods may exceed the allowable range when used in dry soil, making measurement impossible. In such scenarios, it has been necessary to lower the resistance by sprinkling water around the electrode or to drive the auxiliary earthing rods into the ground at a number of different locations in an attempt to find an acceptable value. In addition, since up to 20 m of measurement cable has to be strung to connect the grounding resistance meter and auxiliary earthing rods, users have been faced with long setup and cleanup times.

The FT6031 is an earth tester that meets user requirements by resolving these issues.



Appearance of the FT6031

II. OVERVIEW

The FT6031 is a digital earth tester. By broadening the allowable range of resistance values for auxiliary earthing rods by a factor of 10 compared to that of legacy instruments, it dramatically reduces the need to drive auxiliary earthing rods into the ground at a number of different locations. In addition, the included cable winders halve the amount of time required to wind up measurement cables compared to legacy models, dramatically improving the efficiency of measurement work, including setup and cleanup.

III. FUNCTIONS AND FEATURES

A. One-touch Automatic Measurement

Before measuring grounding resistance, it is necessary to consider two factors that influence measurement. The first is noise known as ground potential, which is caused when leak current flows in the ground, and the second is the resistance of the auxiliary earthing rods. Only when these values have been checked and found to be within their respective allowable ranges can the measurement of grounding resistance begin. Whereas legacy instruments required that these checks be performed separately, the FT6031 checks all necessary conditions with a single press of the MEASURE button and then checked values are found to be acceptable.

Once measurement is complete, users can check each auxiliary earthing rod's resistance value and ground potential by pressing the DISPLAY button.

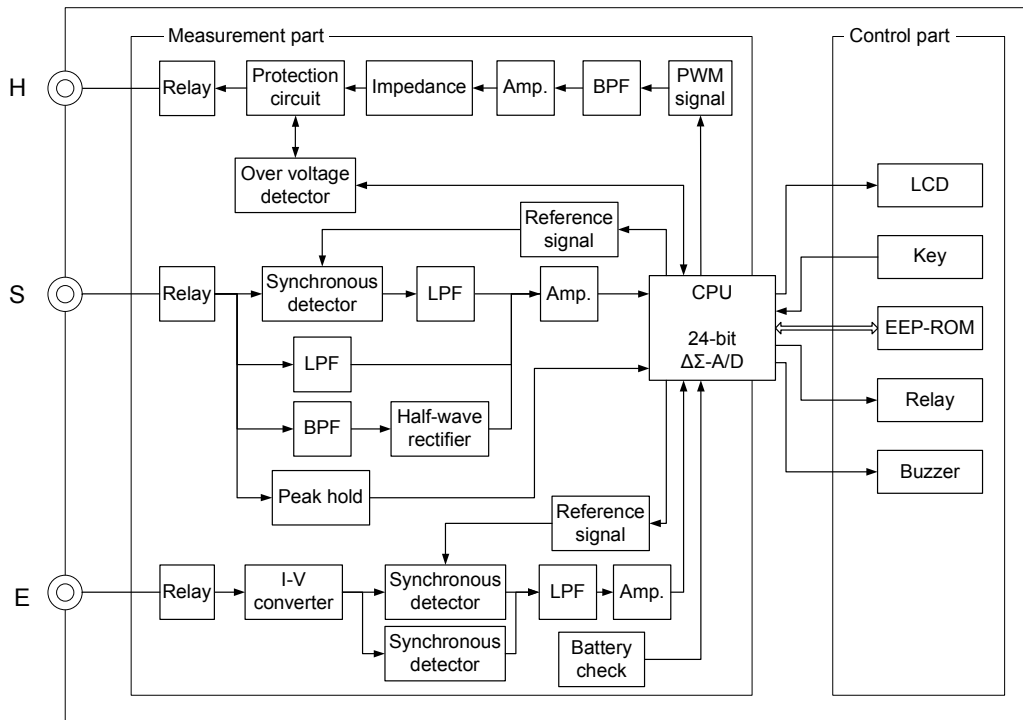


Fig. 1. FT6031 Block Diagram

B. Auto-range Operation

The FT6031 automatically selects the optimal range from its three ranges (20/200/2000 Ω) depending on the magnitude of the grounding resistance.

C. Expanded Allowable Range for Auxiliary Earthing Rod Resistance Values

The larger the resistance value of the auxiliary earthing rod (H), the smaller the measurement current flowing to the ground. The allowable range for the auxiliary earthing rod's resistance value is determined by how minuscule a signal the instrument can measure.

The FT6031 expands this allowable range to 50 k Ω , a 10 \times improvement over legacy models. This enhancement dramatically reduces the need to drive auxiliary earthing rods into the ground at a number of different locations in an attempt to find an acceptable value.

D. Dustproof and Waterproof Enclosure

Hioki improved the FT6031's dustproof performance so that it could withstand use in harsh, dust-filled environments. Since the instrument is routinely placed on the ground during use, the company also improved its waterproofness to allow it to be rinsed with water. The enclosure keeps out water even when the instrument is submerged at a depth of 1 m for 30 min.

E. Measurement Cable With Winders

Hioki has provided winders that allow measurement cables of up to 20 m in length to be efficiently rewound. The new reels can rewind cables up to twice as quickly as the simple design used by legacy models.

F. Drop-proof Design

The FT6031 features a rugged design that can be equipped with a protector so that it can withstand being dropped onto concrete from a height of 1 m.

G. International Standards

The FT6031 complies with IEC 61557, an international standard governing earth testers.

IV. PRINCIPLES

A. Grounding Resistance Measurement

The basic principle of grounding resistance measurement consists of applying a sine wave to the target, measuring the current and voltage signals, and performing a series of calculations.

Fig. 1 provides an overall block diagram for the FT6031. The measurement signal is a 128 Hz sine wave that is obtained by using a band pass filter (BPF) to demodulate a pulse width modulation (PWM) signal with a carrier frequency of 8.192 kHz that is output from the CPU.

The sine wave is amplified by an amplification circuit and then output by a circuit that serves as a constant voltage

source. Since the impedance used to limit the current includes a coupling capacitor for removing the DC component, the magnitude of the current signal and the phase difference between the current signal and the constant voltage source vary with the connected load. Consequently, the current signal is synchronously detected using two reference signals that are 0° and 90° out of phase with the constant voltage source in order to calculate the magnitude of the current and the phase difference. If the real component of the measured value is given by I_{Re} and its imaginary component is given by I_{Im} , the absolute value $|I|$ of the current signal and the phase difference θ with the constant voltage can be calculated using (1) and (2) below:

$$|I| = \sqrt{I_{Re}^2 + I_{Im}^2} \quad (1)$$

$$\theta = \tan^{-1} \left(\frac{I_{Im}}{I_{Re}} \right) \quad (2)$$

In addition to the grounding resistance, which is a pure resistance component, the measurement target includes an inductance component and a capacitance component. The latter two components cause the phase difference that arises between the current signal and the voltage signal. To calculate the pure resistance component alone, it is necessary to measure a voltage signal with the same phase as the current signal.

Consequently, the CPU outputs a reference signal with the same phase as the current signal based on the phase difference θ calculated with (2), and that signal is used to detect the voltage signal. If the measured value is given by V_{Re} , the grounding resistance R_x can be expressed by (3) below:

$$R_x = \frac{V_{Re}}{|I|} = \frac{V_{Re}}{\sqrt{I_{Re}^2 + I_{Im}^2}} \quad (3)$$

Fig. 2 provides a block diagram for the Earth HiTester 3151, an older model. The 3151 uses the AC potentiometer method, which involves measuring the resistance value by adjusting a standard resistance so that the voltage that results from applying the measurement current to a slide rheostat that serves as the reference is the same as the voltage associated with the grounding resistance.

If the current that flows to the E terminal is given by I , the voltage associated with the standard resistance R_s is equal to $R_s I/n$ since the current that flows to the transformer's secondary side is multiplied by the reciprocal of the winding number ratio. Meanwhile, the voltage $R_x I$, which occurs when the current I flows to the grounding resistance R_x , is detected at the S terminal. By adjusting the

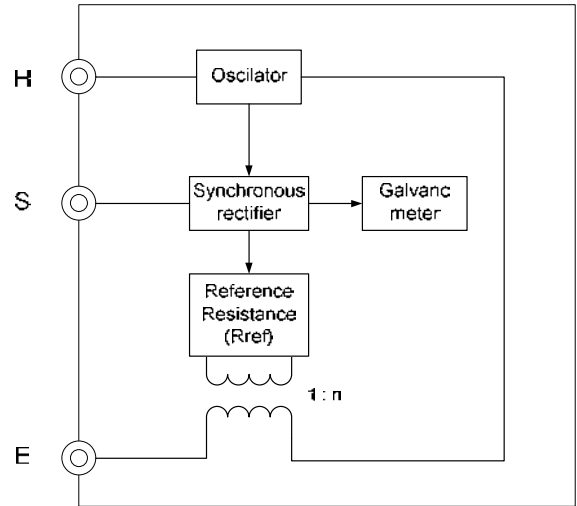


Fig. 2. Block Diagram for the 3151

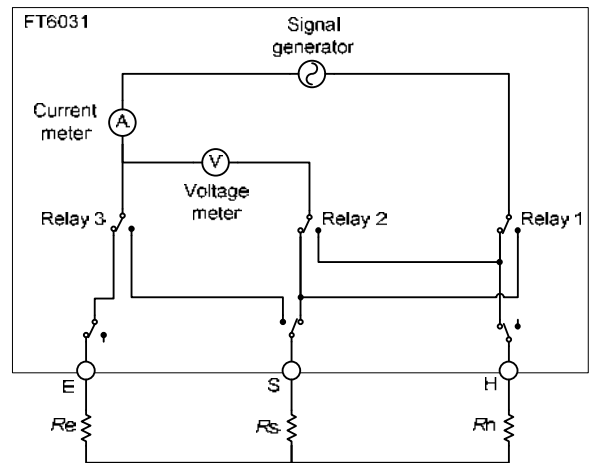


Fig. 3. Schematic for the FT6031

standard resistance R_s so that the two values are equal, the grounding resistance R_x can be calculated using (4) below:

$$R_x = \frac{R_s}{n} \quad (4)$$

In this way, whereas the 3151 calculates the measurement resistance based on its ratio with the standard resistance rather than measuring the current and voltage values separately, the FT6031 is distinguished by measuring the current signal and voltage signal separately and then calculating the resistance value.

B. Automatic Measurement of Auxiliary Grounding Resistance

Fig. 3 provides a schematic diagram of the FT6031. By switching relays placed close to the H, S, and E terminals, the auxiliary grounding resistance values R_h and R_s can be calculated from a total of three measurement results.

For example, to measure the resistance value R_{he} between the H and E terminals, the relays are controlled so that current flows between the H and E terminals, and the voltmeter is connected between the H and E terminals. R_{he} is expressed by (5) below:

$$R_{he} = R_h + R_e \quad (5)$$

Similarly, the resistance value R_{hs} between the H and S terminals and the resistance value R_{se} between the S and E terminals are expressed by (6) and (7) below, respectively:

$$R_{hs} = R_h + R_s \quad (6)$$

$$R_{se} = R_s + R_e \quad (7)$$

Based on the system of equations laid out in (5) through (7), the auxiliary grounding resistance values R_h and R_s are calculated using (8) and (9) below, respectively:

$$R_h = \frac{R_{he} + R_{hs} - R_{se}}{2} \quad (8)$$

$$R_s = \frac{-R_{he} + R_{hs} + R_{se}}{2} \quad (9)$$

V. ARCHITECTURE

A. Hardware

1) Sine wave output unit

The sine wave that serves as the measurement signal is generated by the CPU's PWM function. After using a BPF to remove the carrier wave component and DC component from a sine wave modulated at a frequency of 8.192 kHz (i.e., after demodulating it), the signal's amplitude is increased from 0.5 V rms to 28 V rms by an amplification circuit.

Since the sine wave output unit functions as a constant voltage source, the current that flows varies with the connected load. Consequently, the maximum current that can flow to the load is limited to 25 mA rms by the current-limiting impedance.

2) Current measurement unit

After the measurement current flowing from the H terminal to the E terminal is converted to a voltage by an I-V converter, the signal component is extracted by means of synchronous detection. To allow detection using two reference signals with different phases, the current signal is input to two synchronous detection circuits. The detected

signal is band-limited by an LPF with a cutoff frequency of 9.5 Hz.

3) Voltage measurement unit

The voltage signal detected at the S terminal is detected by means of a reference signal whose phase is the same as the current signal. To remove frequency components other than the measurement signal, the signal's band is limited by incorporating a third-order LPF with a cutoff frequency of 4 Hz after the detection circuit. In addition, the signal level is adjusted by a $1 \times$ to $200 \times$ gain amp to allow measurement to at least three digits of dynamic range.

4) A/D converter

The CPU's two built-in $\Delta\Sigma$ A/D converters are used to perform A/D conversion of the current and voltage signals. Since the A/D converters are independent modules, it is possible to perform A/D conversion of the current and voltage simultaneously. The over-sampling rate (OSR) is variable from 32 to 1,024 and can be selected according to the application (high-speed or high-resolution).

5) AC/DC voltage measurement unit

AC/DC voltage measurement circuits are provided to measure the AC and DC components of ground potential noise. The AC and DC measurement circuits limit the signal band with a 3.2 Hz to 5.3 kHz BPF and a 2.6 kHz LPF, respectively. The AC and DC components are measured alternately, and the larger of the two is displayed as the measured value.

6) Peak voltage measurement unit

To verify that the peak value of the ground potential noise together with superimposed harmonic components does not exceed the measuring instrument's allowable range, the peak voltage is measured using a peak hold circuit that is separate from the AC/DC voltage measurement circuits. A/D conversion is performed using the CPU's built-in 10-bit successive approximation A/D converter.

B. Mechanisms

1) Instrument

Fig. 4 illustrates the FT6031's design. The instrument consists primarily of upper and lower cases, a circuit board, a battery cover, and a protector.

- Dustproof and waterproof design

The design incorporates gaskets between the upper and lower cases and between the lower case and the battery cover. In addition, the hardware for the measurement terminals has been insert-molded into the upper case to provide dustproof and waterproof protection.

- Controls

To prevent water and dust from accumulating on the front of the enclosure, membrane switches, which lack bumps and gaps, have been used for control buttons. Membrane switches were also chosen to ensure electrical isolation.

- LCD

Cushioning material has been placed around the LCD to keep it from cracking in the event the instrument is dropped.

- Protector

A bag-shaped protector keeps dirt and sand from getting into the instrument from the bottom when it is placed on the ground. The protector can be removed.

2) Auxiliary Earthing Rod L9840

By moving from a diameter of 11 mm (used in legacy models) to 6 mm, the L9840 is designed to be easy to drive into the ground. In addition, it features stainless steel construction to ensure adequate strength.

3) Measurement Cable L9842 (With winder)

Fig. 5 depicts the L9842. The reel uses a narrower-diameter axis of rotation for lower frictional resistance so that the cable can be paid out smoothly. Since the auxiliary earthing rods and measurement cables are carried together, the side of the winder incorporates holders for stowing the rods.

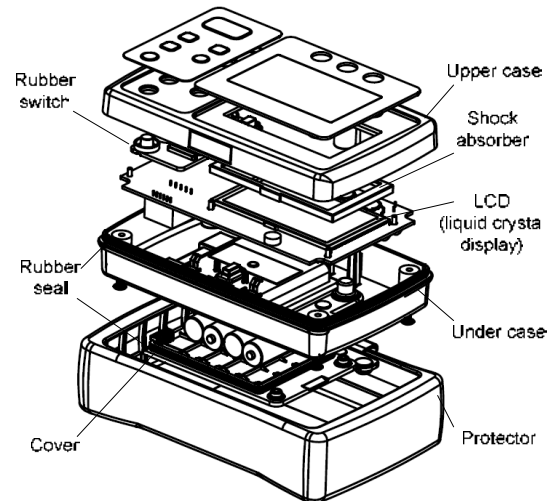


Fig. 4. Instrument Design

VI. CHARACTERISTICS

A. Accuracy

Fig. 6 illustrates the FT6031's accuracy, which is expressed using an indicator known as reading error. Reading error indicates how much error measured values incorporate relative to the true value. For comparison purposes, the figure includes measurement results for the 3151, a legacy model. The graph illustrates that the FT6031 includes an extremely small error within the measurement range of 1 Ω to 1 k Ω .

B. Effects of Ground Potential Noise

Figs. 7 and 8 illustrate the results of simulating the addition of ground potential to the measurement circuit by connecting a voltage generator in series with a measurement resistance of 10 Ω . A voltage of at least 10 V (the level at which the product is guaranteed to function) was input and the instrument's performance verified. Thanks to the steep band limiting after synchronous detection, the FT6031 is resistant to the effects of ground potential.

C. Effects of Auxiliary Earthing Rod Resistance

Fig. 9 illustrates the effect of the resistance value of the auxiliary earthing rod (H) on measured values, while Fig. 10 illustrates the effect on measured values when a resistance of 10 Ω is measured while varying the resistance value of the auxiliary earthing rod (S) from 10 Ω to 50 k Ω . The graphs make it clear that there is almost no effect on the FT6031's measured values, even when the resistance of the auxiliary earthing rod is 50 k Ω .

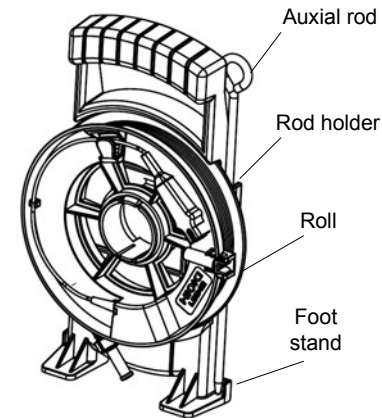


Fig. 5. Appearance of the L9842

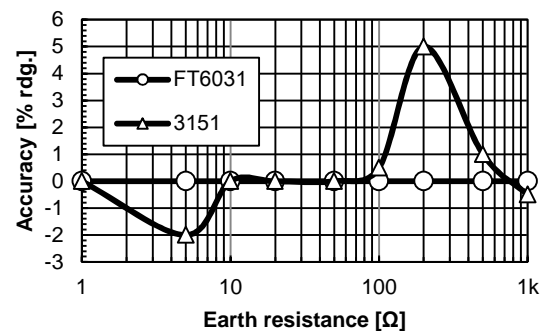


Fig. 6. Accuracy

Earth Tester FT6031

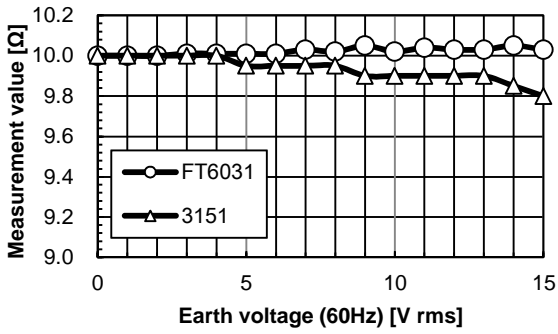


Fig. 7. Effects of Ground Potential (60 Hz)

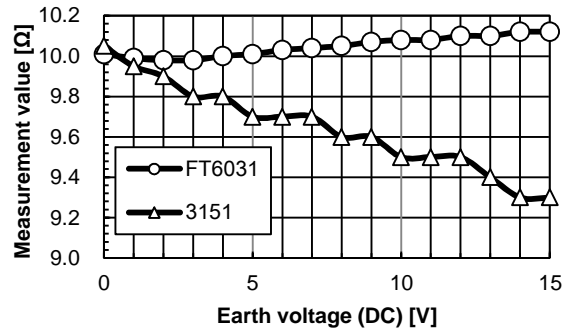


Fig. 8. Effects of Ground Potential (DC)

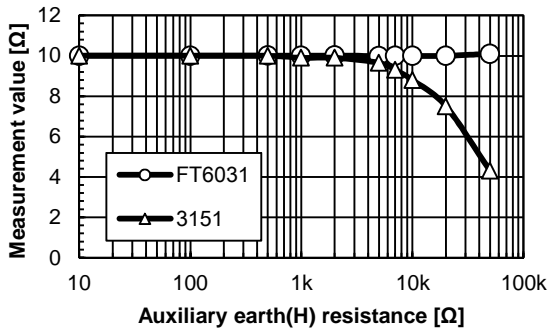


Fig. 9. Effects of Auxiliary Earthing Rod (H) Resistance

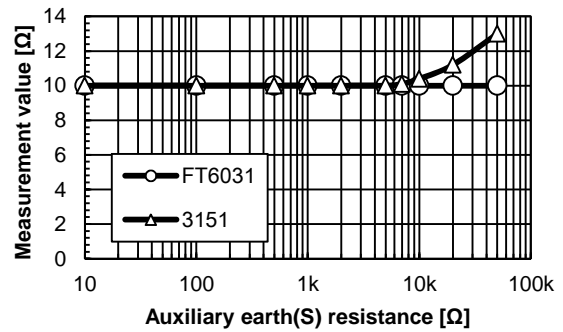


Fig. 10. Effects of Auxiliary Earthing Rod (S) Resistance

VII. CONCLUSION

The FT6031 is a grounding resistance meter that delivers high environmental resistance along with improved work efficiency in the field. It is hoped that the instrument will find use among a broad customer base.

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REFERENCE

[1] Kawase, T.; Takahashi, T. Secchi Gijutsu Nyumon (Introduction to Grounding Technology). 1986, pp. 1-33. Ohmsha. (Japanese).

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