Lux Meter FT3424

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Abstract—**The Lux Meter FT3424, which qualifies as a General Class AA device under JIS C 1609-1, has received type approval (No. EE141) under Japan's Measurement Act. The instrument is an illuminometer that has the high-precision luminosity characteristics required for use in plants where next-generation lighting fixtures such as LEDs are manufactured and in locations where such lighting has been installed. This paper provides an overview of the product and describes its features, architecture, and other characteristics.**

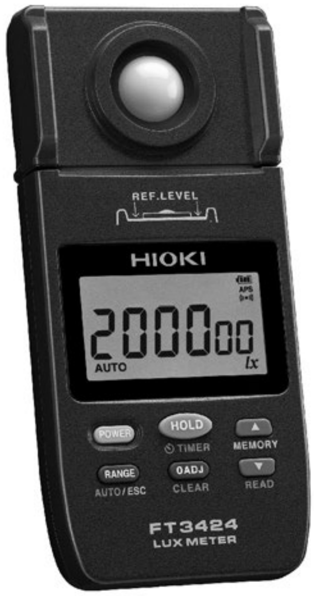
I. Introduction

Illuminance is defined as a physical quantity that expresses the brightness of light as perceived by the human eye. One of its uses is as an indicator of brightness in school classrooms and company offices, where it aids in judging the proper amount of light. Illuminometers are used in such settings.

In recent years, there has been a noteworthy move toward broad adoption of LED lighting as a next-generation lighting technology, creating numerous opportunities for measuring illuminance in plants where LED lighting fixtures are manufactured and in locations where such lighting has been installed. Such applications require an illuminometer that qualifies as a General Class AA device under the general measuring instrument standard JIS C 1609-1:2006. However, the legacy Lux HiTester 3423 offered General Class A performance under that standard, necessitating development of a General Class AA illuminometer that satisfies the category's more rigorous requirements in such areas as spectral sensitivity characteristics.

II. Overview

Hioki developed the Lux HiTester 3421 in 1979 and subsequently developed and launched the Digital Lux HiTester 3422 and the Lux HiTester 3423. A large number of these instruments remain in use in luminance measurement applications in such fields as lighting installation and facility management. In recent years, the industry has seen an increasingly diverse range of light source and light modulation technologies emerge for use in LED and other types of lighting, which are attracting attention as next-generation lighting solutions, including the adoption of pulse width modulation (PWM) technology. In some cases, older illuminometers cannot be used with pulsed light, which is characterized by large fluctuations in illuminance (see Section V-*C*).



Appearance of the FT3424

The standards that govern illuminometers have also evolved, with the old JIS C 1609-1 standard, which predated widespread adoption of LED lighting, being scrapped in 2006 and replaced with JIS C 1609:2006 for general measuring instruments, as described in Section III-*A* below, and JIS C 1609-2:2008 for specified measuring instruments (those used in transaction or certification applications).

These changes comprise the backdrop against which Hioki developed the Lux Meter FT3424 as a high-precision illuminometer that qualifies as a General Class AA device under the JIS C 1609-1:2006 standard for general measuring instruments and launched the device for use in a broad range of applications, including next-generation lighting research and development, manufacture, and installation. The instrument has also received type approval under Japan's Measurement Act, ensuring a high level of reliability when used in transaction or certification applications.

Hioki's success in developing a high-precision luminosity filter played a major role in the development of the FT3424.

III. Functions and Features

In developing the FT3424, Hioki identified “usability in the field” as a key product concept. The product was developed with a strong awareness of the fact that it would be used in the field despite being a precision optical measuring instrument. With its color-coded control keys, which provide operators with an intuitive understanding of the necessary measurement functions, and a large LCD designed to make illuminance values easy to read, the FT3424 provides a readily approachable level of operability. Thus equipped with an easy-to-read display and simple-to-use controls, the FT3424 is an illuminometer that will help boost work efficiency.

A. *General Class AA Qualification (JIS C 1609-1)*

Compared to the old JIS standard, JIS C 1609-1 incorporates more rigorous requirements that match illuminometers’ spectral sensitivity characteristics with their luminosity characteristics. Specifically, the tolerance for the divergence of relative spectral response characteristics in the visible region from the standard spectral luminous efficiency has been tightened to 3/4 of the level required by old JIS standard. The FT3424 incorporates a redesigned illuminance sensor that takes advantage of high-precision filter technologies perfected during the development of the LED Optical Meter TM6101 to deliver a luminosity filter whose high level of precision ranks it among the best in the industry. Since the illuminometer’s spectral sensitivity characteristics approach the standard spectral luminous efficiency, it can measure light sources with different light spectra, for example LED lighting and organic EL lighting, with a high degree of precision.

B. *Excellent Measurement Range Coverage*

The FT3424 provides an extensive selection of measurement ranges, from a 20 lx range for low-illuminance measurement to a 200,000 lx range for high-illuminance measurement. In particular, the 20 lx range delivers high resolution of 0.01 lx, making it ideal for use in low-illuminance measurement in locations such as emergency lighting and emergency exit signage, which are subject to regulatory provisions in Japan’s Fire Service Act.

C. *Separate Sensor and Display*

The FT3424’s sensor and display can be undocked and connected with the optional Connection Cable L9820 so that the sensor to be positioned independently of the display. This capability is intended to accommodate the need to place the sensor separately in lighting installations so that the measurement technician’s own shadow does not affect illuminance values. As illustrated in Fig. 1, a technician can place the sensor in the measurement location and then check the illuminance from a distance.

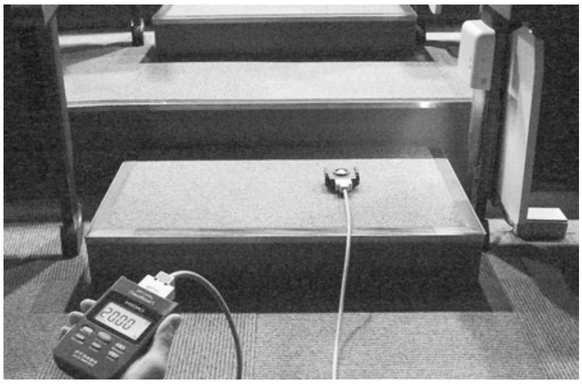


Fig. 1. Separate Sensor and Display

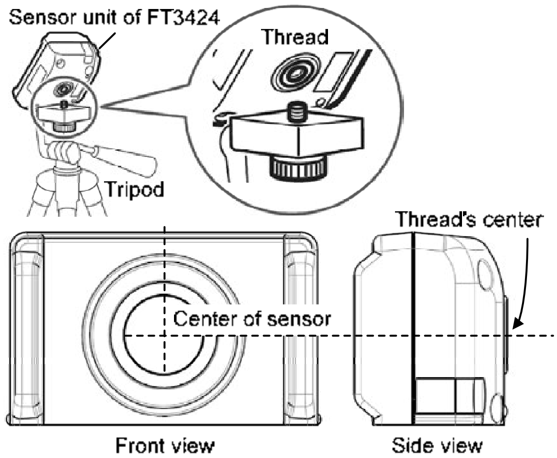


Fig. 2. Mounting the Sensor on a Tripod

In lighting fixture manufacturing plants, measurements are often made after securing the sensor at a predefined position. To accommodate such use, Hioki has provided a screw hole on the back of the sensor so that it can be mounted on a tripod as illustrated in Fig. 2.

D. *Timer Hold Function*

The FT3424’s timer hold function fixes the illuminance value once a preset time has elapsed after the TIMER key is pressed, allowing the measurement technician to move away from the measurement target where the illuminometer has been set up before the timer runs out. This function is designed so that the technician’s own shadow does not affect illuminance values.

E. *Memory Function*

The FT3424’s internal memory can store up to 99 data points.

The instrument’s memory function saves the illuminance value in the device’s internal memory each time the MEMORY key is pressed. Each saved data point is assigned a number in the order it was saved, and the instrument can store up to 99 such data points. The illuminance values associated with particular data numbers can be recalled later for review.

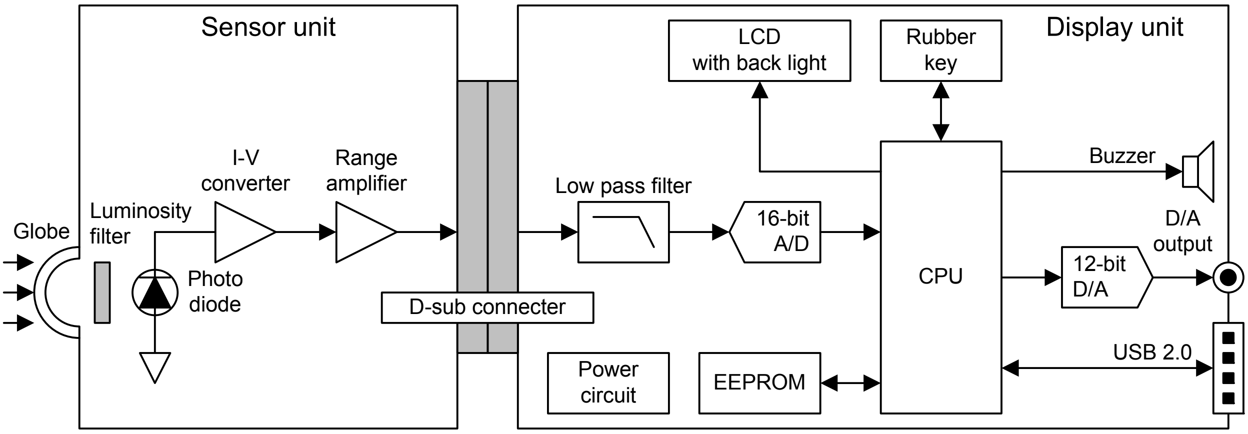


Fig. 3. Block Diagram

This function is convenient when using the instrument in applications that require multiple measurements, for example when carrying out illuminance measurement in accordance with the Ministry of Education, Culture, Sports, Science and Technology's standard for school environmental sanitation. When testing classrooms, the technician must measure illuminance at nine predefined locations and then verify that the minimum value is at least 300 lx (a value of 500 lx or greater is desirable) and that the ratio of the maximum illuminance value to the minimum illuminance value does not exceed 10:1. The FT3424's memory function can be used to save the nine illuminance values to the instrument's internal memory for later retrieval so that a judgment can be made, or for batch transfer to a computer using its USB communication functionality, which is described below.

F. USB Communication Functionality

The FT3424 can be connected to a computer via its USB interface. Supported functionality includes transferring all data stored in the instrument's internal memory to a computer (see Section III-*E*), controlling the instrument via application software, making measurements at a set interval, and transferring data. Fig. 4 illustrates an example in which the application software is being used to record data. Illuminance values can be graphed so that fluctuations can be visualized.

Hioki expects this capability to find use in applications in which fluctuations in illuminance must be recorded over extended periods of time and in testing of illuminance during the manufacture of lighting fixtures.

G. D/A Output Functionality

The FT3424's D/A output functionality enables it to convert displayed illuminance values into a voltage signal for output to an external device. Illuminance values are converted using 2 V DC for the maximum valid display of 2,000 counts in each measurement range and output based on the display refresh interval.

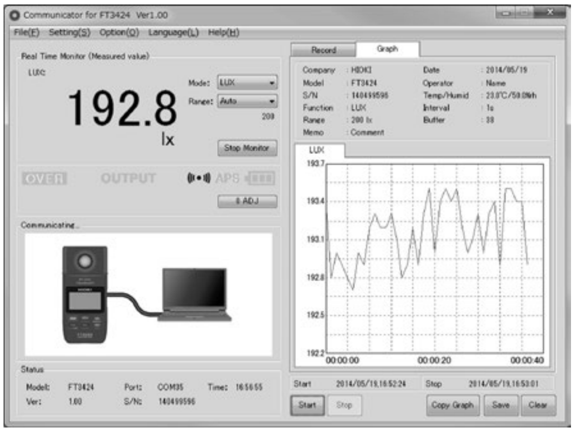


Fig. 4. Recording Data Using USB Application Software

By combining the FT3424 with other recording and measuring instruments via the D/A output terminal on its side, it is possible to perform continuous illuminance measurement or record illuminance fluctuations.

H. Protective Ridges for Sensor

The design of the FT3424's sensor unit is distinguished by two protective ridges on the left and right sides of the unit that sit higher than the sensor's light-sensing surface. These ridges protect the illuminance sensor from damage if the sensor is placed upside-down on a floor, for example. In this way, the unit has been designed to protect the illuminance sensor from scratches and dirt that would adversely affect measurement precision.

I. Type Approval (No. EE141)

In a sign of its high level of reliability, the FT3424 has received type approval. Under Japan's Measurement Act, only illuminometers that have passed a verification process can be used to make measurements that are used in transaction or certification applications. In particular, illuminance measurements carried out as part of the installation or replacement of lighting fixtures in public parks and on public roads must be made using an illuminometer that has passed such a verification process. The FT3424 has received a type approval number so that it can be used in situations such as these where a verified instrument is required.

IV. Architecture

The FT3424 consists of a sensor unit that incorporates the actual illuminance sensor and a display unit that incorporates a large LCD display and operation keys. Fig. 3 provides a block diagram for the instrument.

A. Sensor Unit

The illuminance sensor on the sensor unit consists of a light-collecting unit that incorporates a globe and a high-precision luminosity filter, and a board that incorporates a light-sensing element. Fig. 5 illustrates how these parts have been combined.

After passing through the globe and high-precision luminosity filter, incident light strikes the light-sensing element, which generates current according to the human eye's luminosity. This current is miniscule, on the order of several picoamperes for low illuminance values or several dozen microamperes for high illuminance values. The current is converted into a voltage signal by an I-V converter.

Fig. 6 illustrates an I-V converter that uses an amplifier. The current generated by the light-sensing element flows to the output side of the amplifier via a feedback resistance. If this current is I and the feedback resistance is R, the voltage given by ($I \times R$) will characterize the amplifier's output. Despite the minuscule magnitude of this current, conversion to a suitable voltage level is handled by means of feedback resistance switching using analog switches since a wide range of currents must be handled. The amplifier and analog switch used here have been carefully chosen based on their current-related characteristics so that the measurement current is not affected.

Up to this point, signal processing has been handled by the sensor unit. In particular, the I-V converter has been implemented using minuscule current measurement technology, one of Hioki's core strengths. By combining circuit technology and filter technology, it is possible to achieve stable measurement at low illuminance levels as well as measurement that can accommodate PWM-modulated light (see Section V-*C* below).

B. Display Unit

In addition to a large LCD display and a number of key switches, the display unit incorporates a D/A output terminal (mini-jack) and USB mini-receptacle on its side. On the rear is a compartment housing the two LR6 or R6 (AA) batteries that serve as the instrument's power source.

Compared to the sensor unit, the display unit has a simple structure. As illustrated in Fig. 7, this structure consists of two boards, a large LCD display, and key switches that are sandwiched between front and back cases.

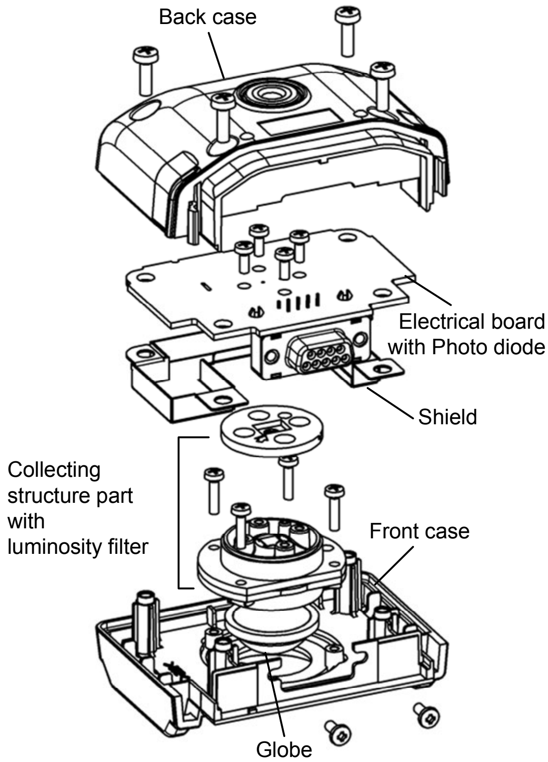


Fig. 5. Structural Diagram of the Sensor Unit

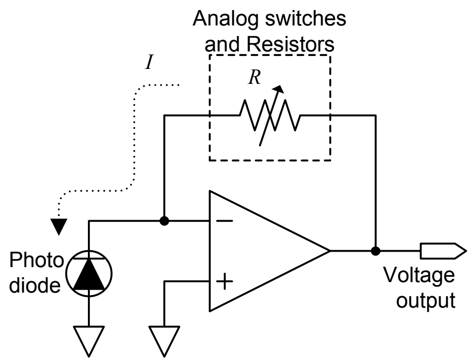


Fig. 6. I-V Converter

1) Measurement and display

The electrical circuit acquires the voltage signal that corresponds to the illuminance from the sensor unit with an A/D converter and transfers the resulting data to the CPU, which converts the values into illuminance values by means of software processing. Illuminance values are displayed with four significant digits and up to 2,000 counts per range. Consequently, when an illuminance value exceeds 2,000 lx, it is converted and displayed with the lowermost digit fixed to 0 (in the 20,000 lx range) or the two lowermost digits fixed to 00 (in the 200,000 lx range).

2) Power sources

The FT3424 can operate on either of two power sources: two LR6 or R6 (AA) batteries or USB bus power. When operating on USB bus power, the circuit shuts off the supply of power from the batteries.

The power supply circuit is designed to deliver a high level of efficiency while using less power and requiring fewer electrical components. As a result, the instrument can operate continuously for 120 hours (about three times the Lux HiTester 3423's 40 hours) when powered by R6 (AA) manganese batteries or for about 300 hours when powered by LR6 (AA) alkaline batteries.

3) USB communication

Hioki utilized the CPU's built-in USB 2.0 module for USB communication in order to reduce the number of parts in the instrument.

The circuit uses a novel design that lets it supply bus power even if USB communication capability is not being used, and it performs software processing.

4) D/A output unit

The D/A output unit outputs voltage data based on illuminance values when the dedicated Output Cord 9094 is connected to the instrument's D/A output terminal. The circuit is designed so that the CPU monitors the D/A output terminal and halts voltage output if the 9094 is not connected.

5) Large LCD display

Anticipating use in the field, the instrument's large LCD display is equipped with a backlight. Unlike other measuring instruments, the backlight on an instrument designed to measure illuminance must not affect illuminance measurements. Consequently, the backlight only operates when the display value is being held by the hold function or the timer hold function while the instrument is in an environment characterized by an illuminance of 750 lx or less.

The illuminance measurement circuit operates continuously, and the illuminometer's status is monitored by software so that the instrument can determine whether the backlight can be operated without issue.

V. Optical Characteristics

This section describes the representative optical characteristics of the proprietary high-precision luminosity filter used by the FT3424.

A. Relative Spectral Response Characteristics in the Visible Region

The human eye perceives green as bright and purple and red as dim, even if the light sources in question are emitting light at the same level of energy. The International Commission on Illumination (CIE) has defined sensitivity to the color (wavelength) of light in the form of spectral luminous efficiency by averaging measurements taken using a large number of subjects. Spectral luminous efficiency in the wavelength region of 360 nm to 830 nm characteristically peaks at 555 nm.

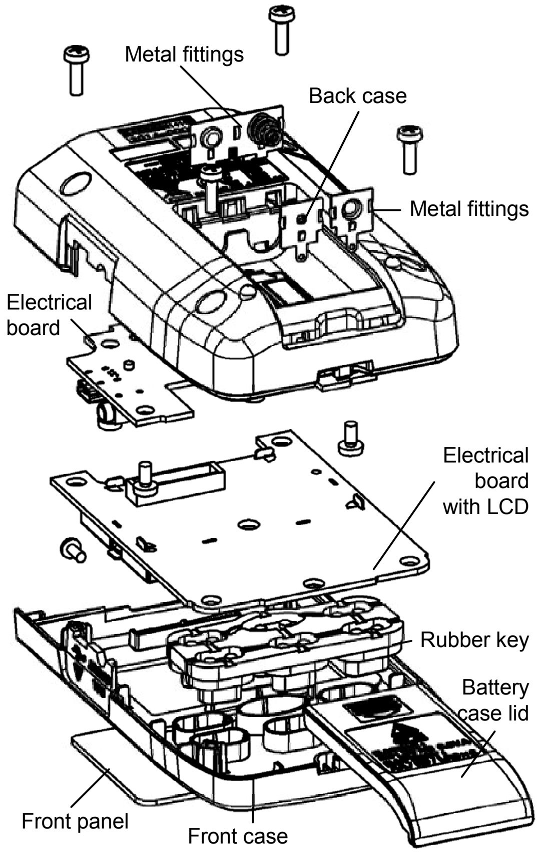


Fig. 7. Structural Diagram of the Display Unit

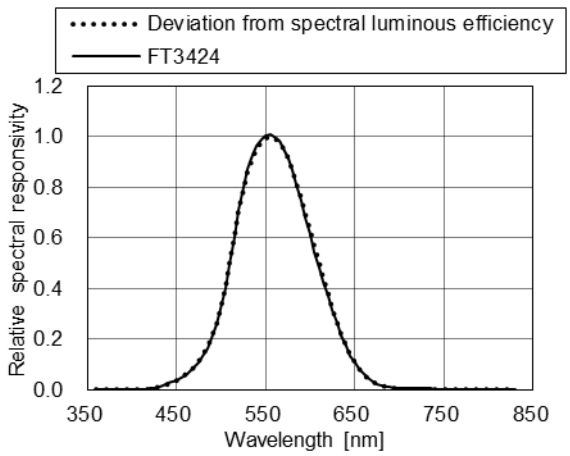


Fig. 8. Relative Spectral Response Characteristics in the Visible Region

As illustrated in Fig. 8, the FT3424's relative spectral response characteristics resemble the spectral luminous efficiency. If the divergence f_1' from the spectral luminous efficiency $V(\lambda)$ as calculated using the equation for relative spectral sensitivity set forth in JIS C 1609-1:2006 is 6% or less, the device in question is considered to satisfy the performance requirements for a General Class AA device.

According to JIS C 1609-1:2006, f_1' is calculated using (1) and (2) below:

$$f_1' = \frac{\int_{\lambda_1}^{\lambda_2} \left| S'(\lambda)_{rel} - V(\lambda) \right| d\lambda}{\int_{\lambda_1}^{\lambda_2} V(\lambda) d\lambda} \times 100 \qquad (1)$$

$$S'(\lambda)_{rel} = \frac{\int_{\lambda_1}^{\lambda_2} P(\lambda)_A V(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} P(\lambda)_A S(\lambda)_{rel} d\lambda} S(\lambda)_{rel} \qquad (2)$$

$P(\lambda)_A$: Relative spectral distribution of standard illuminant A
$V(\lambda)$: Spectral luminous efficiency
$S(\lambda)_{rel}$: Relative spectral response
$d\lambda$: Measurement wavelength interval
λ_1: Visible wavelength region lower limit
λ_2: Visible wavelength region upper limit

As illustrated in Fig. 9, the value f_1' for the FT3424 test sample more than satisfies the 6% limit value for a General Class AA device, indicating that the instrument delivers excellent response sensitivity.

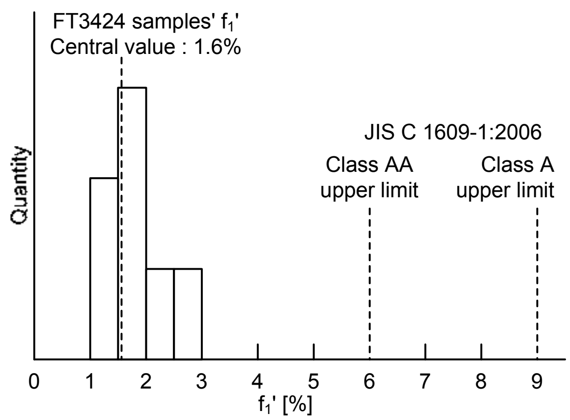


Fig. 9. Distribution of f_1' for FT3424 Test Samples

B. Oblique Incidence Characteristics

Since illuminance is defined as exposure to luminous flux per unit of area, if the surface receiving the luminous flux is positioned at the angle θ relative to the light source, the illuminance will exhibit cosine characteristics by being attenuated in proportion to cosθ. Fig. 10 illustrates the FT3424's oblique incidence characteristics.

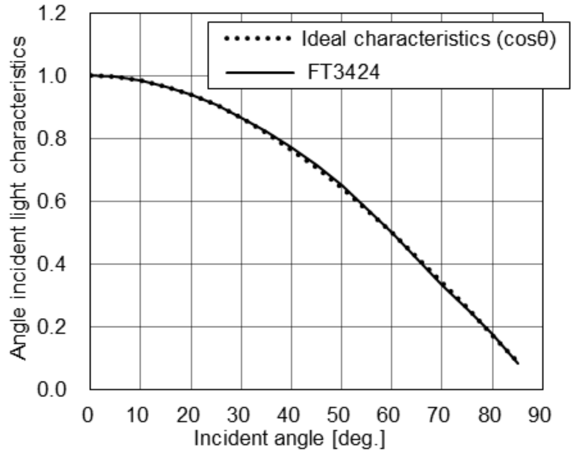


Fig. 10. Oblique Incidence Characteristics

According to JIS C 1609-1:2006, the angle of incidence in the normal direction for an illuminometer's light-sensing surface is 0°, and the systematic divergence f_2 exhibited by the oblique incident light characteristics is calculated by performing an oblique incident light test in which illuminance values are read while positioning the light-sensing unit in 10° increments in an area from 10° to 80° around the vertical axis that passes through the intersection between the light-measuring axis and the measurement reference surface. The performance of the illuminometer in question can be determined based on the calculated f_2 value. f_2 can be calculated using (3) and (4) below:

$$f_2^*(\theta) = \left| \frac{Y(\theta)}{Y_0 \cos\theta} - 1 \right| \times 100 \qquad (3)$$

$$f_2 = \int_0^{\frac{80^\circ \pi}{180^\circ}} \left| f_2^*(\theta) \right| \sin 2\theta \, d\theta \qquad (4)$$

θ: Angle of incidence (°)

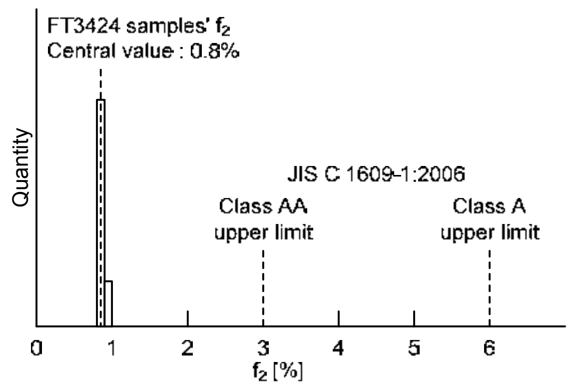


Fig. 11. Distribution of f_2 for FT3424 Test Samples

As a result of this calculation, and as illustrated in Fig. 11, the value f_2 for the FT3424 test sample more than satisfies the 3% limit value for a General Class AA device, indicating that the instrument delivers excellent oblique incidence characteristics.

C. Effects of Pulsed Light

Unlike steady lighting, whose light source is illuminated at all times, LED and many other recent lighting technologies use PWM light modulation, which results in pulsed light created by repeatedly cycling the light source on and off. The legacy Lux HiTester 3423 was compatible with steady light but not PWM-modulated light in some instances. For example, the instrument indicated low illuminance values when used to test PWM-modulated light with significant variations or low-duty pulsed light. The FT3424 can be used with low-duty pulsed light, and it can accurately measure the illuminance of PWM-modulated light as well.

As an example, TABLE I lists the deviation between measurements of steady light (for which the amount of light does not change) and measurements of pulsed light (for which the on duty was changed, where “on” refers to the light being on and “off” to its being off), both taken with the FT3424. These results indicate that the instrument is little affected by the saturation of pulsed light, as illustrated in Fig. 12. Even including slight fluctuations in the equipment and light source used in the test, the results reveal a deviation of less than 0.5%.

TABLE I. DEVIATION BETWEEN STEADY LIGHT AND PULSED LIGHT (40 HZ)

ON Duty [%]	FT3424 Deviation [%]				
	20 [lx]	*200* [lx]	*2000* [lx]	*20000* [lx]	*200000* [lx]
1	−0.05	0.05	0.05	0.16	−0.28
3	0.10	0.05	0.05	−0.16	−0.36
10	−0.05	0.00	0.00	0.20	0.26
30	0.00	−0.10	0.05	−0.16	0.27
90	0.00	0.16	0.00	0.00	0.00
99	−0.05	−0.05	0.05	−0.05	−0.05
100	0.00	0.00	0.00	0.00	0.00

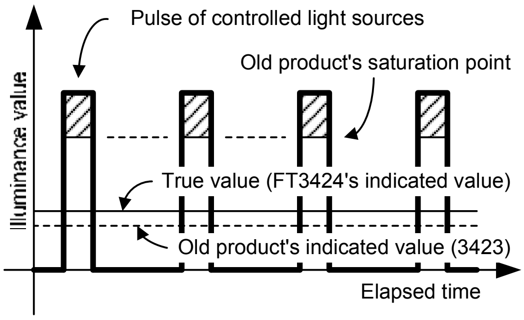


Fig. 12. Effect of Pulsed Light Saturation

D. Temperature Characteristics

Under JIS C 1609-1:2006, General Class AA instruments must have temperature characteristics such that the deviation in luminance values at −10°C ±2°C (14.0°F ±3.6°F), 0°C ±2°C (32.0°F ±3.6°F), 10°C ±2°C (50.0°F ±3.6°F), 30°C ±2°C (86.0°F ±3.6°F), and 40°C ±2°C (104.0°F ±3.6°F) is within ±3% using the value for 23°C ±2° (73.4°F ±3.6°F) as a reference. As illustrated in Fig. 13, results for the FT3424 test sample indicate that the instrument delivers performance within ±3% from −10°C to 40°C (14.0°F to 104.0°F). Hioki also carried out a temperature characteristics test with an enlarged temperature range from −20°C to 60°C (−4.0°F to 140.0°F) to reflect the standard operating temperature range of its field measuring instrument product group and were able to confirm that the deviation is within ±1%.

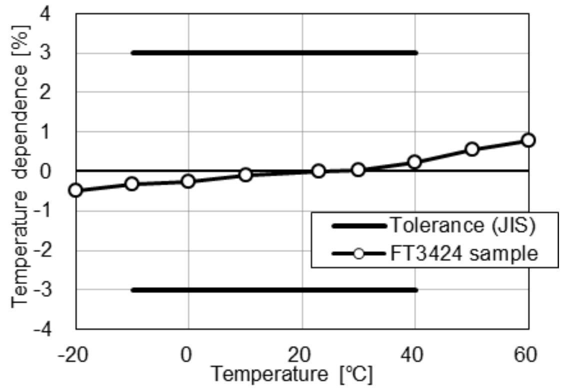


Fig. 13. Temperature Characteristics of FT3424 Test Sample

E. Low-illuminance Range Linearity

The broad coverage of the FT3424’s measurement ranges was introduced in Section III-*B* as a key feature of the instrument. Fig. 14 illustrates the linearity deviation for a number of test samples in the low-illuminance 20 lx range, which is particularly important. The maximum linearity deviation values for the 20 lx range for all test samples were within ±0.5%. These results demonstrate that the FT3424 delivers high-resolution, high-precision illuminance measurement at low illuminance levels.

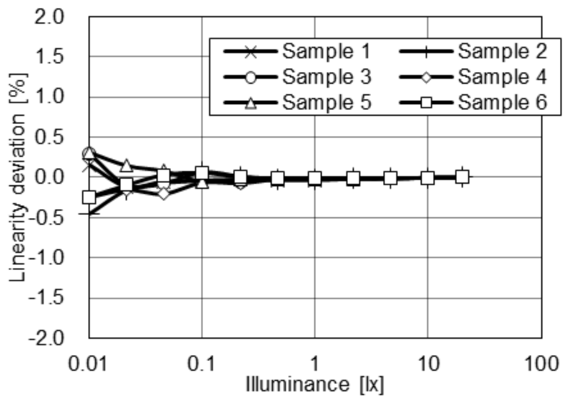


Fig. 14. Linearity Deviation in the 20 lx Range

VI. Use as a Legally Authorized Illuminometer

The FT3424 has received type approval from the Minister of Economy, Trade and Industry in accordance with the Measurement Act, and the instrument can be used in transaction or certification applications once it has been subject to verification. Once an FT3424 has been verified, it will bear the verification seal on its enclosure, enabling it to be used as a legally authorized illuminometer for a period of two years. Once the verification period has ended, the instrument can be re-verified.

The FT3424 has received type approval as follows:

Model: FT3424
Type: Digital
Manufacturer: Hioki E.E. Corporation
Type approval number: No. EE141
Date of type approval: August 18, 2014

VII. Conclusion

The FT3424 is a high-precision illuminometer that qualifies as a General Class AA device under JIS C 1609-1:2006, and it has received type approval under the Measurement Act, signaling that it delivers the reliability required for use in transaction or certification applications. An extensive range of field measuring instrument design technologies—one of Hioki’s core strengths—were incorporated during the development process, yielding a robust and easy-to-use product. Hioki expect the FT3424 to see use as a reliable field measuring instrument in the same broad range of fields as legacy illuminometers.

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