Built-In Color Sensor

B5WC

User’s Manual

Built-In Color Sensor

E612-E1-01

Note

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- The content of this manual is subject to change without notice for the purpose of improvement.
- If you have any question or comments, please contact our sales representative listed at the end of this manual.

  Please notify the manual number described at the end of this manual as well.

Table of Contents

Safety Precautions

To ensure safe operation, be sure to read and follow the Terms and Conditions Agreement.

⚠WARNING

These products cannot be used in safety devices for presses or other safety devices used to protect human life. This product is designed for use in applications for sensing workpieces and workers that will not affect levels of safety.

⚠CAUTION

This product is not designed or rated for ensuring safety of persons either directly or indirectly.
Do not use it for such purposes.

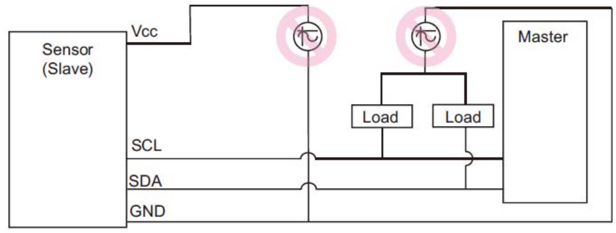
Precautions for Safe Use

To ensure safety, observe the following precautions.

•Wiring

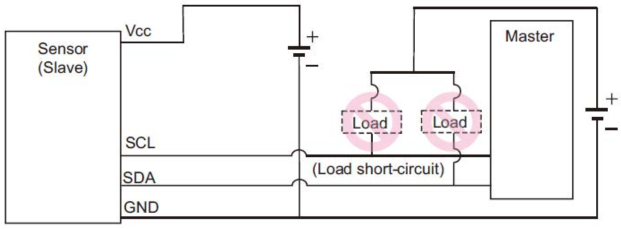
Power supply voltage

Do not use the product with a voltage or current that will even momentarily exceed the specified voltage or current range.
Applying a voltage or current exceeding the specified voltage or current range or using an AC power supply may result in rupture or burning.



Load Short-circuit

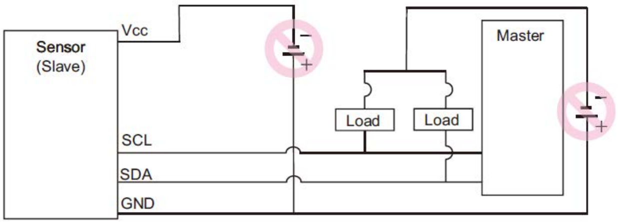
Do not short-circuit the load. Rupture or burning may occur.



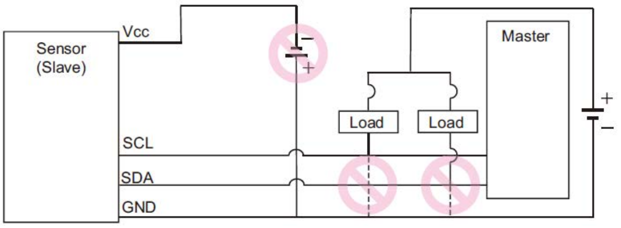
Faulty Wiring

Do not miswire such as the polarity of the power supply voltage.
Rupture or burning may occur.

Example 1. Wrong polarity

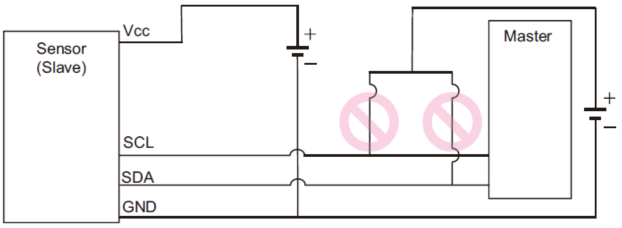


Example 2. Wrong polarity and faulty wiring



Connection without Load

If the power supply is connected directly without a load, rupture or burning of the internal elements may occur.
Connect a load when wiring.



Storage and Operating Environment

1. Places where the product is not exposed to corrosive gases, such as hydrogen sulfide gas, or salty wind.
2. Places where it is not exposed to direct sunlight.
3. Make sure that flux, oil, or other chemicals do not adhere to the surface of the emitter and receiver.
4. Do not apply a load that may deform or deteriorate the product in any circumstances.
5. Store the product in a normal temperature, humidity, and pressure environment.
6. The product should be used without freezing or condensation.
7. Do not use the product in atmospheres or environments that exceed product ratings.
8. This product does not have a water-proof and oil-proof structure.
   Therefore, do not use the product in an application or environment where it will be subject to water, oil, chemicals, or any other liquid getting directly on it.

Precautions for Correct Use

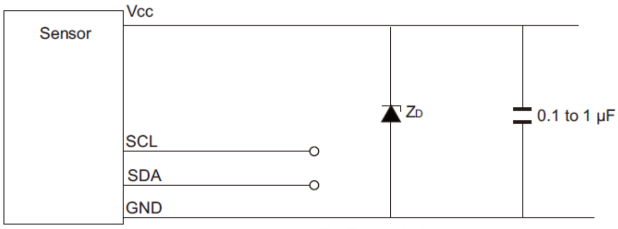
●Mounting

1. This sensor is designed to be built into equipment. Design the equipment structure so that ambient light does not enter into the sensor. When using the equipment where the sensor will be influenced by ambient light, install it so that the sensor will not be affected by ambient light.
2. Mount the sensor securely on a flat surface. To retain the sensor with screws, use M3 screws (to prevent the screws from loosening, use a spring washer and a flat washer with a diameter of 6mm). Use a tightening torque of 0.54 N·m max.
3. Take care that nothing comes into contact with the detected part of the sensor. Damage to the sensing element will result in poor performance.
4. Before using the sensor, check to make sure that it has not become loose due to vibration or shock.
5. When using the sensor with a moving part, secure the part of the cable that is pulled out so that stress will not be directly applied to it.

●Wiring

Surge Prevention

1. If there is a surge in the power supply, try connecting a Zener diode or a capacitor (with a capacitance of 0.1 to 1 μF), depending on the operating environment. Use the sensor only after confirming that the surge has been eliminated.



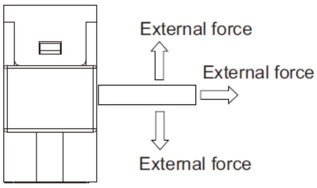
ZD: Zener diode

2. Do not use a small inductive load, such as a relay.
3. Separate the wiring for sensors from high-voltage lines or power lines. If the wiring is routed in the same conduit or duct as such lines, the sensors may malfunction or may be damaged by inductive interference.
4. When attaching the connectors, make sure that they are inserted into the housing properly.

●Handling during Wiring

Surge Prevention

1. If a force is applied to the connection area between the terminal and connector by bending or pulling the cable after the wiring is completed, the connector contact part or connection area with the cable may be damaged, resulting in contact failure.
2. Make sure that a stress (external force) as shown in the figure below is not applied to the connection area between the terminal and connector when routing and connecting cables or harnesses.
3. Do not perform cord wiring when power supply voltage is applied. Doing so may result in breakage.



●Design

Modulated-light sensors

When designing, give proper consideration to the influence of the power supply and cable length.
Since this sensor is a modulated-light sensor, it is more easily affected than non-modulated light sensors.

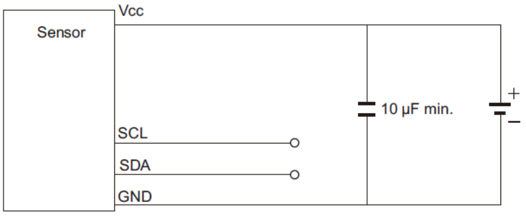
Reasons for Interference from Power and Cable Length on the sensors with Modulated Light

An LED emitter is pulse-lighted to produce modulated light.
A large current momentarily flows to the sensor in sync with this pulse timing. This causes a pulsating consumption current. A photoelectric sensor incorporates a capacitor with sufficient capacity, and is virtually unaffected by the pulse of the consumption current. With a small sensor, however, it is difficult to have a capacitor with a sufficient capacity. Accordingly, when the cable length is long or depending on the type of power source, it may become impossible to keep up with the pulse of the consumption current and operation may become unstable.

Countermeasures

Adding a Capacitor

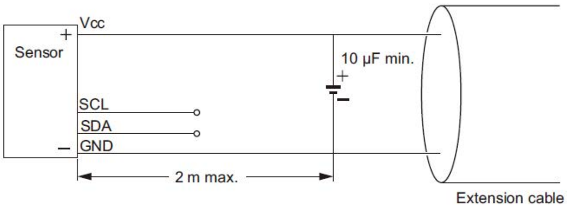
Attach a capacitor of 10 μF min. as close as possible to the sensor when wiring.
(Use a capacitor with a dielectric strength that is at least twice the sensor's power supply voltage. Do not use tantalum capacitors. A short-circuit may cause the capacitor to ignite due to the large current flow.)



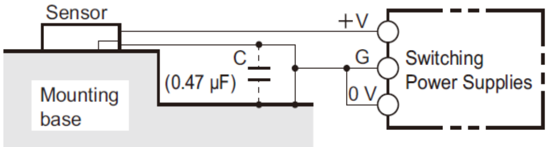
Countermeasures for Switching Power Supplies

Take either of the following countermeasures as required if connecting a modulated-light sensor to a switching power supply.

1. Attach a capacitor (e.g., aluminum electrolytic capacitor) of 10 μF min. as close as possible to the sensor when wiring.
(Use a capacitor with a dielectric strength that is at least twice the sensor's power supply voltage. Do not use tantalum capacitors. A short-circuit may cause the capacitor to ignite due to the large current flow.)

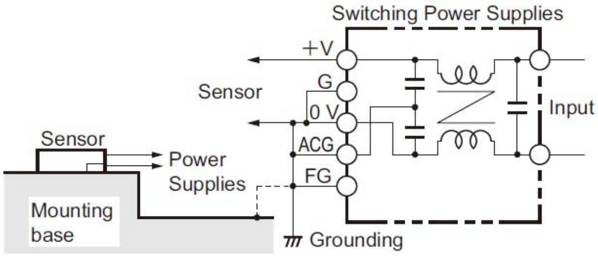


2. Connect to the 0-V line of the power source or connect by way of a capacitor (approx. 0.47 μF) at the point closest to the sensor to reduce the impedance of the sensor mounting base so that it is difficult for inductive noise to enter the mounting base.



3. Connect the noise filter terminal (neutral terminal to ACG) of the switching power supply to the case (FG) and 0-V terminal of the power supply.
The line connected as mentioned above should be grounded or connected to the mounting base to ensure stable operation.
(Recommended by power supply manufacturers.)

Countermeasures to Handle Inductive Noise



Insert a plastic insulator of approximately 10 mm between the sensor and the mounting base.

Effects of Inductive Noise

When there is inductive noise in the sensor mounting frame (metal), the output of the sensor may be affected. In this case, ensure that there is no electrical potential difference between the sensor 0-V terminal and the sensor mounting frame (metal).
Or, put a 0.47-μF capacitor between the 0-V terminal and the frame.

●Other precautions

1. Do not mount the sensor in the following places because doing so may cause malfunction or failure.
   1) Place exposed to a lot of dust or oil mist
   2) Place exposed to a lot of corrosive gas
   3) Place directly or indirectly exposed to splashes of water, oil, or chemicals
   4) Outdoors or place exposed to intensive light such as direct sunlight
2. The sensor may be dissolved by exposure to organic solvents, acid, alkali, aromatic hydrocarbon, and chlorinated aliphatic hydrocarbon solvents, causing deterioration in the characteristics.
Do not expose the sensor to such chemicals.
3. An output pulse may occur when the power supply is turned ON due to the power supply environment and other influences. Use the sensor in the stable ready-for-detection state reached in 100 ms after turning on the power supply.
4. When the number of averaging times is set to a low value, variations in the RGB output values may increase due to A/D conversion errors, noise, and other factors. We recommend checking the RGB output values multiple times.
5. If the sensor is used outside the power supply voltage range, set the power to OFF (0 V) once because there is the possibility of unexpected operation.
6. If foreign matter has adhered to the lens, the output voltage may vary. When removing foreign matter from the lens, take care not to touch the lens with a hand, etc. so as to prevent it from getting scratched or dirty.
7. Use a power supply of max. 15 W for the power supply connected to this sensor because the internal circuit does not have a safety device.
8. When disposing of the product, please dispose of it as industrial waste.

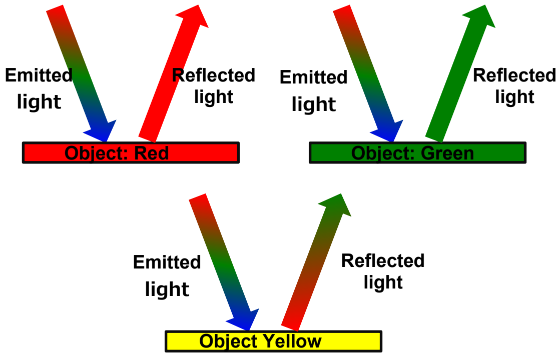
1 Overview

This User's Manual describes the usage and special notes of B5WC, the color sensor to build into equipment.

This document is intended to supplement the datasheet and product specifications, which should be referenced when using the sensor.

2 Structure

The built-in color sensor B5WC is composed of a white LED light source with a wide wavelength range of visible light, an RGB photo IC with a PD (photo diode) that detects light in each of the three primary colors of light (red, green, and blue), an optical lens, an internal circuit with the MCU, and other dedicated components.



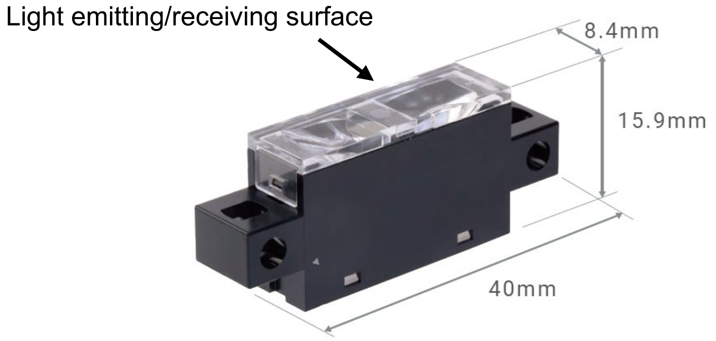
<Principle>

- White LED light emitted from the color sensor reflects off the surface of the sensed object, and the reflected light is focused by the optical lens and enters the RGB photo IC.
- The light reflected from the sensed object contains R/G/B wavelength regions that provide color information, and the RGB photo IC detects each of the received light intensity. This light intensity value is converted into R/G/B output voltage value.
- The RGB output voltage value is loaded from an upstream system via the I^2C bus.

3 Dimensions

Shown below are the dimensions of the color sensor. Refer to the datasheet for details.

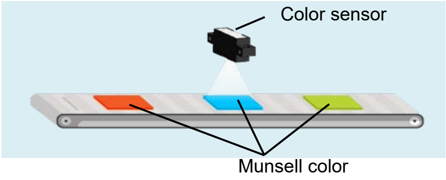
Note that the external dimensions and screw mounting hole dimensions are the same as those of OMRON's light convergent reflective type sensor B5W-LB21 series.



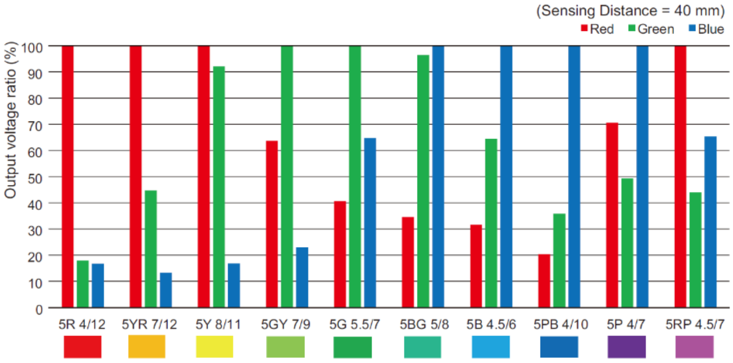
4 Product Features

The color sensor is a type of reflective optical sensor that detects the color of the sensed object by the received R/G/B light intensity. These received RGB light measurements allows judgment of the color of sensed objects.

Shown below is the Munsell color detection capacity diagram indicating the ratio of each voltage value to the maximum voltage value when the maximum output voltage value of the color sensor is set as 100%. The ratio of RGB data changes according to the Munsell color.



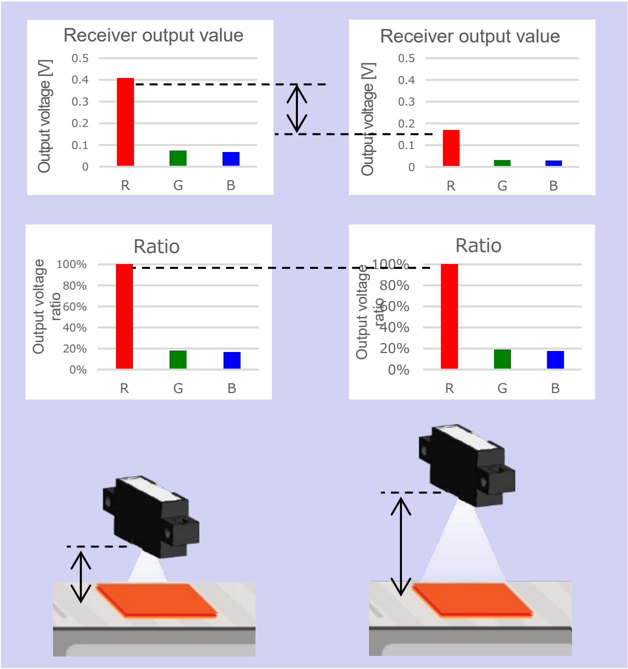
Conceptual Image of Measurement



Munsell color detection capacity

Another feature of color sensors is that the RGB ratio remains virtually unchanged as the sensing distance changes.

The charts below show the receiver output of the color sensor and the receiver output ratio when the sensing distance changes. Since the color sensor is a type of reflective optical sensors, the receiver RGB output value changes with changes in sensing distance, but the receiver RGB output ratio remains almost unchanged. This is because the sensor detects not only the light intensity reflected from the sensed object, but also the RGB wavelength components contained in the reflected light. This makes it possible to stably differentiate the color of sensed objects even when the sensing distance to the object changes due to flapping or other factors.



← As sensing distance changes, receiver output value also changes.

← Even if sensing distance changes, receiver RGB output ratio does not change.

5 Usage (Detection)

Shown below are the electrical and optical characteristics described in the product specifications for Model B5WC-VB2322-1.

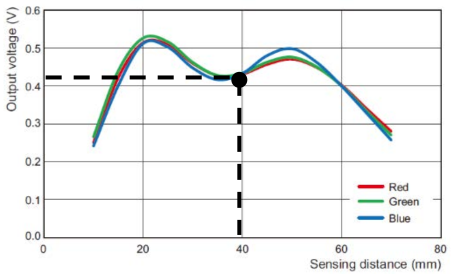
Since this sensor is used in applications to detect various objects, the output voltage value is defined by a gray color reference board that is achromatic. Omron uses gray as its standard because gray is a color in which all RGB wavelength regions are theoretically equal.

Item Model	**B5WC-VB2322-1**
Sensing distance	40 mm (white paper)
Light source	White LED
Power supply voltage	5 VDC ±5%
Current consumption	18 mA max. (at 5.25 VDC)
Communication method	I^{2}C
I^{2}C output	Output voltage value for each of red, green and blue: 0.45 V ±20% (when gray reference plate and detection distance of 40 mm) Output saturation voltage: Typ. 2.75 V (output voltage range: 0 to 2.75 V) SCL/SDA input H voltage: 2.54 to 5.4 V, input L voltage: 0.9 V max., SDA output L voltage 0.44 V max. (when output current of 3 mA) RGB output voltage value resolution: 3.2 mV
Sampling period	1 msec

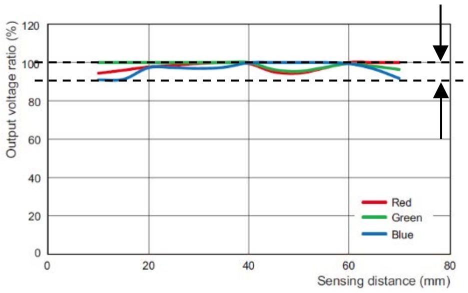
The optical characteristics of the sensor can be confirmed mainly by the characteristic diagram that graphically shows the receiver output of the color sensor versus sensing distance and the ratio of receiver output. The characteristics diagrams shown below are charts that indicate the relationship between the sensor output voltage and sensing distance for various sensing objects.

For example, the product specifications for the RGB output voltage values for a gray reference plate are given as TYP:0.45V @d=40mm, which means that the output voltage at a sensing distance of 40mm in the following "Receiver output and Sensing distance characteristics" is around 0.45V for each of RGB.

The RGB output voltage ratio to this gray color reference plate is shown in the receiver output ratio and distance characteristic diagram (informative), which indicates that the difference in the RGB output ratio is within about 10% or less even when the sensing distance changes in the range of 10 to 70mm.



Receiver Output - Sensing Distance Characteristics



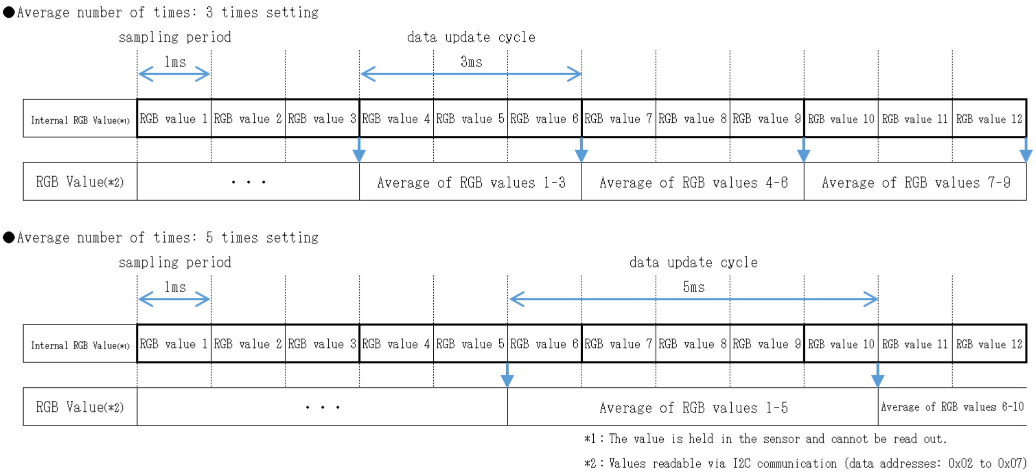
Receiver output ratio - Sensing Distance Characteristics

When designing the structure of the equipment to which the color sensor is incorporated, the distance between the sensor and the sensing object should be determined by referring to the "Receiver output − Sensing distance characteristics". In the case that the sensing object position does not fluctuate, the sensing distance is recommended to be set at the position within the range from 30 to 50mm where the characteristics curve is relatively small.

■Sampling period and average number of times

This sensor acquires RGB values at each sampling period of 1 msec. An additive average filter process is then performed in the sensor to update the output RGB values. Shown below is the relationship between the average number of times and the data update cycle.

Data update cycle = Sampling period (1 msec) x Average number of times

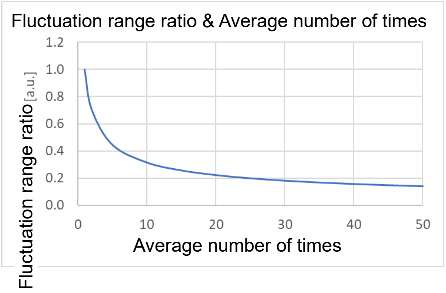


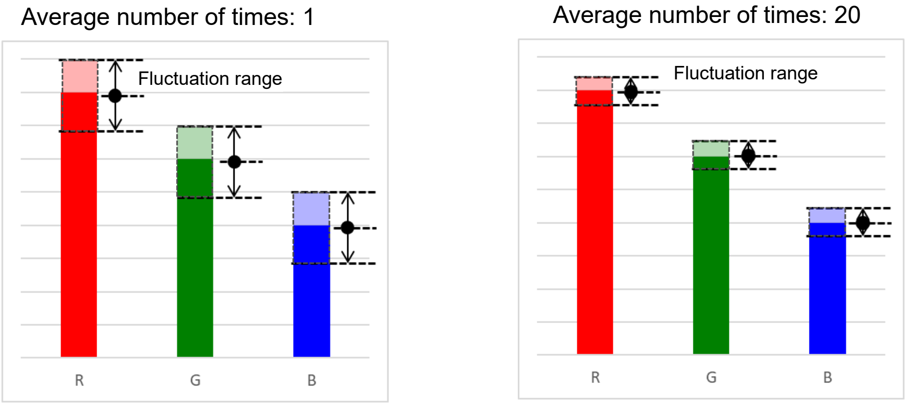
*1 : The value is held in the sensor and cannot be read out.

*2 : Values readable via I2C communication (data addresses: 0x02 to 0x07)

Average number of times and data update cycle

The average number of times can be configured in the range from 1 to 50. Increasing the average number of times allows control of fluctuations in the output RGB values. Please refer to the chart on the right for an indication of fluctuation control. When the average number of times is set to 20, the fluctuation range of RGB values is suppressed to about 1/5 compared to the average number of times set to 1.




Average number of times: 1

Average number of times: 20

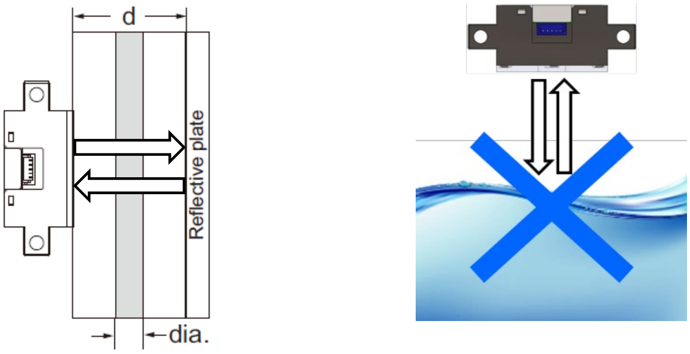
Conceptual image of RGB value fluctuation range and average number of times

Increasing the average number of times also increases the data update cycle. The maximum data update cycle is 50 msec. For applications where the sensing object moves at high speed, set the average number of times according to the moving speed and the timing you wish to measure.

For other details related to the I^2C operation of this color sensor, refer to the product specifications B5W-VB2322-1, Sections 10 to 12, or Appendix: Color Sensor Operation Overview.

■If the sensing object is a liquid

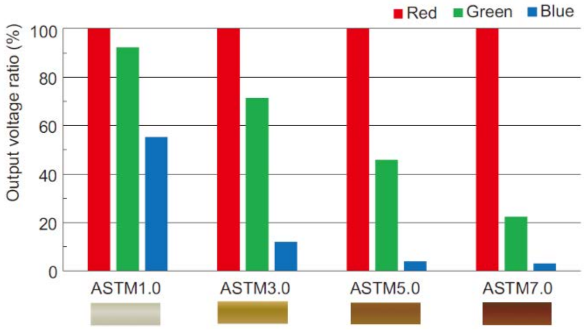
So far, we have described the case where the sensor's light is irradiated on the surface of the sensing object as a general reflective optical sensor, but it can also be used to distinguish differences in the color of liquids in transparent containers. Example schematic diagrams are shown below. As in the diagram, install a reflector on the opposite side of the color sensor and place a transparent container containing the liquid to be detected between them. It is difficult to judge the color of the liquid by irradiating light directly on the surface of the liquid in the container from a color sensor.



Example of liquid color measurement

The following chart shows the results (informative) of liquid color measurements using the above measurement method.

As an example here, a liquid reagent with known color information called ASTM color is used.



d=22 mm
dia.=7 mm
Reflective plate: Stainless steel 430
Detected object: ASTM reagent

RGB output voltage ratio to petroleum product color standard sample* **∗For ASTM Color**

With this measurement method, the color of a liquid in a transparent container can be detected by the color sensor as received RGB light intensity. In this case, however, the RGB output values of the color sensor will vary depending on the installation environment, mainly as described below.

Condition (1) Container size

As shown in the receiver output - sensing distance characteristics of the color sensor, the receiver output also fluctuates when the "container size"(i.e. "distance between the sensor and the reflector") changes. In particular, if the distance is too close (approx. 0 to 20mm) or too far (approx. 50mm or more), it will be difficult to ensure the receiver output. It is recommended that the distance between the sensor and the reflector be within the range of 20 to 50mm.

Condition (2) Reflector material and surface condition

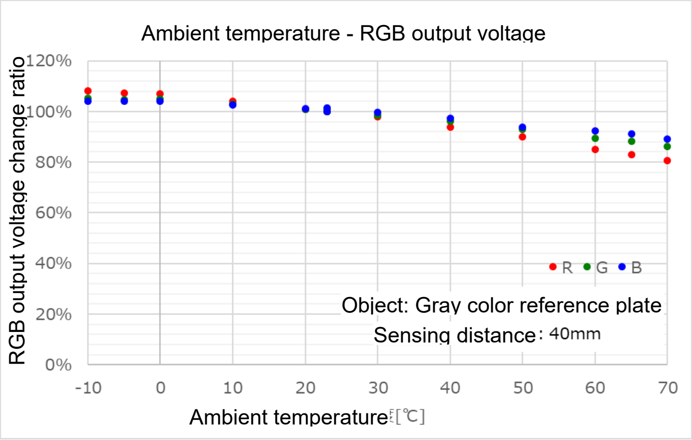
Select the reflector with as uniform a surface condition as possible. For reference, OMRON uses a reflector of "SUS430/surface polished (#240 or #320 equivalent)" in its measurements.

Thus, the RGB output values of the color sensor will fluctuate when either of the above conditions (1) or (2) is changed. Since these conditions vary depending on the customer's application, it is ideal in actual use to conduct a thorough evaluation to determine the optimal combination that will produce the desired RGB output values.

■Others: Reference data

- Sensing distance characteristics and the effect of ambient temperature

The RGB output voltage value of this sensor varies depending on the ambient temperature. Shown below is the reference data.



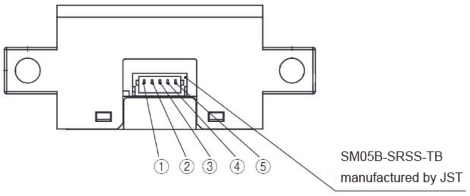
■Use of color sensors in practical applications

As mentioned above, the characteristic values listed in the product specifications specify a gray-colored resin plate equivalent to general Munsell paper as the sensing object. Actual applications, however, generally detect various objects other than that, and it is necessary to evaluate whether the sensor can stably detect the target object in actual equipment over a long period of time. Specifically, it is necessary to measure "Sensing distance − Output voltage" using actual objects to make sure that sufficient output voltage values are obtained to discriminate color differences. As precautions in this case, the smaller the output voltage value, the greater the influence of fluctuations due to noise and other effects. As a result, it may be necessary to take measures to stabilize the output voltage value, such as increasing the average number of times (this is especially true for subtle differences in color). In addition, it is ideal to evaluate as many samples as possible, taking into account the individual variability of the sensor.

6 Usage (Circuit)

1. Connector

This sensor uses a connector for connection. Shown below is the model and terminal function of the connector mounted on the sensor.



Terminal No.	Name
(1)	Vcc
(2)	SDA
(3)	SCL
(4)	Not used.
(5)	GND

You must provide the harness. You also need to select the housing to be connected to the connector. Shown below are the housing and contact listed in the manufacturer's catalog for the connector "SM05B-SRSS-TB (J.S.T. Mfg. Co., Ltd.)" to be mounted on the sensor as reference information.

[Excerpt from the catalog of J.S.T. Mfg. Co., Ltd.]

Housing	With protrusions: SHR-05V-S-B
	Without protrusions: SHR-05V-S
Contact	SSH-003T-P0.2-H

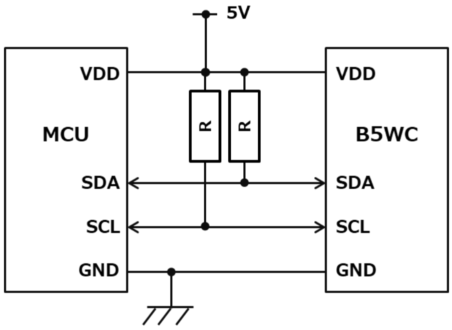
* You must determine the compatibility of the connector on the harness side and that on this sensor.

Note that the connector terminal (4) of B5WC-VB2322-1 is a blank one. Since it is not connected to the internal circuit of the sensor, the operation of the sensor is not affected even if no wire is connected to the terminal (4).

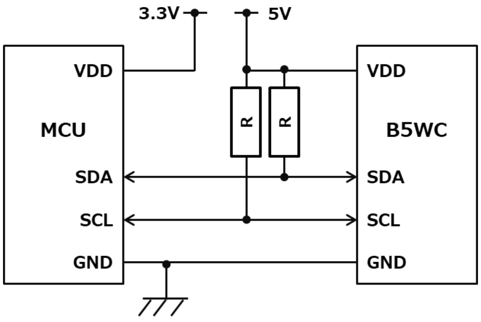
2. Connection example

This sensor is designed for I^{2}C communication. Electrical connection examples are shown below.

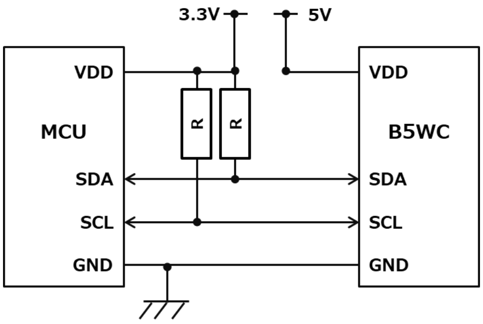
Case 1: 5V MCU direct connection (when microcontroller power supply voltage is the same)



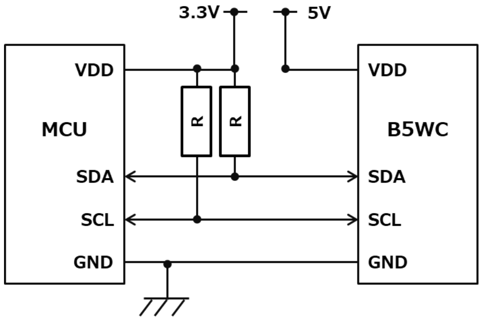
Case 2: 3.3V MCU (I^{2}C port is 5V tolerant)



or



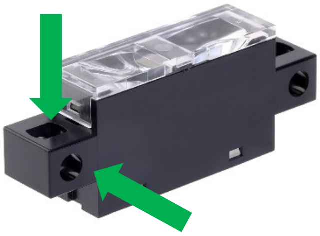
Case 3: 3.3V MCU (not 5V tolerant)



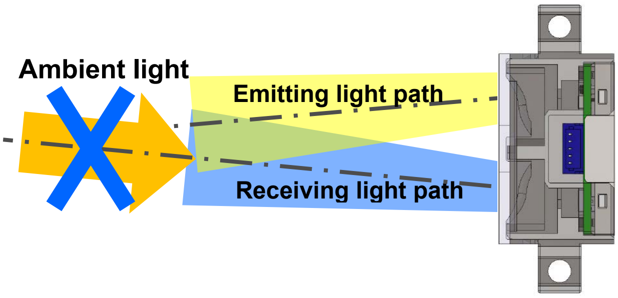
For details of the components specifications, refer to the product specifications B5W-VB2322-1, Sections 10 to 12.

7 Installation Method

1. This sensor can be mounted in two directions, X and Y. Refer to the product specifications for details of mounting.
   * Use M3 screws, spring washers, and flat washers and tighten with torque of 0.54(N·m).



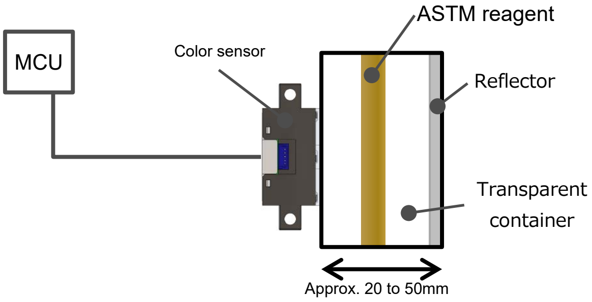
2. The structure of this sensor should be designed with equipment to prevent ambient light from entering. If the sensor's light-emitting or light-receiving block must be exposed to the outside of the equipment for application purposes, the effect of ambient light can be reduced by installing the sensor in such a way that no ambient light enters from the light-receiving path direction. As shown in the figure below, the emitting and receiving light paths of this sensor form a V shape. Therefore, it is necessary to evaluate the sensor sufficiently by considering the direction of sensor installation to prevent ambient light from entering from this direction.



3. This sensor is neither waterproof nor oil resistant. You need to design the structure of the equipment to prevent water, oil, or chemicals from pouring on the sensor. For detailed precautions, refer to the precautions for safe use and precautions for correct use described in the specifications and datasheet.

<Specific examples of usage>

(Example 1) Lubricant color change detection
A conceptual image of the installation is shown below.



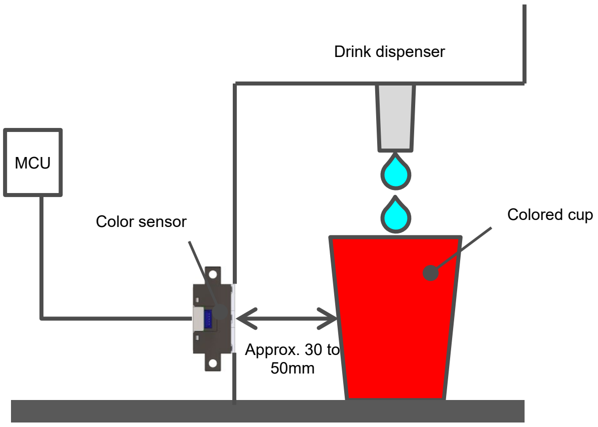
Conceptual image of installation

- Install the color sensor so that the lens surface of the sensor contacts closely to the transparent container. The recommended size range for transparent containers is 20 to 50mm. Attach the reflector so that it contacts closely to the container as well.

- When lubricant enters the container, the color sensor outputs the RGB voltage values. By reading these values via the I^2C bus and identifying the amount of change in the RGB ratio, changes in lubricant color can be detected.

* Select the material of the transparent container according to the type of lubricant. The shape of the container can be either rectangular or cylindrical, but the structure should be such that the positional relationship between the container, sensor, and reflector is fixed.
* Select a reflector that can ensure the received light intensity of the color sensor. For reference, OMRON uses a reflector of "SUS430/surface polished (#240 or #320 equivalent)".

(Example 2) Cup color detection in drink dispensers
A conceptual image of the installation is shown below.



Conceptual image of installation

- Install the color sensor so that the lens surface of the sensor faces the cup to be detected.

- The recommended distance range between the sensor lens surface and the cup is about 30 to 50mm. Within this range, the fluctuation of the RGB output voltage values are relatively small, even taking into account the shift of the cup's placement position.

- When a cup is placed, the color sensor outputs the RGB voltage values. By reading these values via the I^2C bus and comparing with the RGB ratio for each cup recorded beforehand, the cup color can be judged. By presetting the corresponding drink for each cup color, different types of drinks are served in each cup.

* The cup itself can be detected by comparing the output voltage of the color sensor in the absence of a cup and in the presence of a cup of each color. However, if the color of the cup is dark and the RGB output voltages themselves are small, there is a possibility of detecting "no cup" even though there is a cup, or "cup present" even though there is no cup due to ambient light, so sufficient evaluation is required for each application. It is recommended that the cup detection method be provided separately from the color sensor, if possible.

For the above examples as well as other applications, if you have any questions about specific judgment methods using RGB values, please contact us for technical consultation.

8 Frequently Asked Questions

Q: Can the sensor detect color differences of an object with a glossy surface?
A: If a surface of an object to be detected is glossy, some of the white LED light emitted from the sensor will reflect off the surface and enter the photosensitive area. Since this light does not contain color information of the object, it is difficult to accurately detect the color information of the object if it is glossy. In reality, the degree to which color information on the object can be obtained will vary depending on the degree of glossiness. You need to evaluate the detection capability in your actual application and on the object to be detected.

Q: There is a description of how to detect colored translucent liquids, but can the sensor detect color differences of translucent solids (e.g. colored translucent glass or plastic)?
A: If a surface of an object is glossy such as colored translucent glass or plastic with a glossy surface, the sensor cannot accurately detect the color information of the object even if it directly irradiates light as it is. As with liquids, it may be possible to detect color differences if a reflective plate is used to sandwich the translucent object. The precautions in this case are the same as for liquids. For details, refer to 5. Usage (Detection).

Q: How large must the object to be detected be?
A: Ideally, the size of the object to be detected should be larger than the area of the lens surface of the sensor (26.4 x 8.4mm).

Q: How should we deal with ambient light?
A: Design the structure of the equipment so that ambient light does not enter the sensor. If the lens surface of the sensor must be exposed to the outside of the equipment, install the sensor in a direction that prevents ambient light from entering the equipment as much as possible, and fully evaluate the effects of such exposure. For details, refer to 7 Installation Method.

Q: Can the sensor detect color differences even if the object is black or white?
A: Since white and black colors theoretically have the same RGB ratio, it is difficult to distinguish white or black using RGB ratios. On the other hand, there is a difference in the absolute value of the receiver output values between white and black, which can be used to discriminate them. When attempting to discriminate black and white using this method, however, the receiver output of the sensor is affected by factors other than color information, such as distance. Please evaluate the sensor with a thorough understanding of its characteristics and make your own judgment as to whether or not white and black can be distinguished.

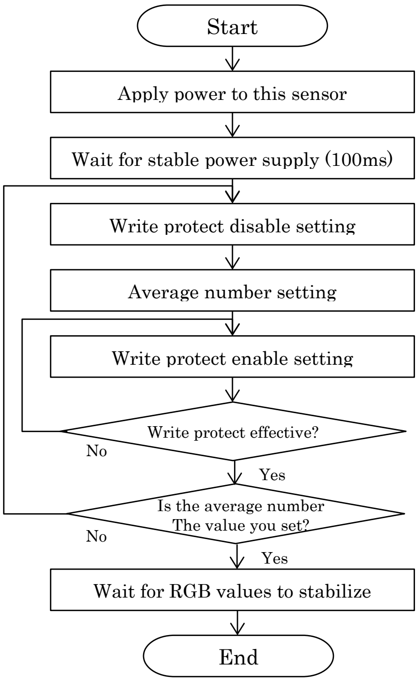
Q: Can the RGB ratio information in the characteristics data on the datasheet be read from the sensor?
A: Only RGB output voltage values can be read from this sensor. You need to calculate the RGB ratio based on the readout RGB output voltage values.

Appendix: Color Sensor Operation Overview

■(Reference) Setting flowchart

The initial configuration example of this sensor is shown below.

We recommend that you follow the flowchart below.



Write protect disabled (0x5A) to data address: 0x00 via I²C communication

Write any average number of times (1~50 times) to data address: 0x00 via I²C communication

Write protect enabled (other than 0x5A) to data address: 0x00 via I²C communication

Read data address: 0x00 via I²C communication
and confirm that Write protect is enabled (other than 0x5A)

Read data address: 0x01 via I²C communication
and confirm that the average number of times matches the set value.

After changing the average number of times, wait for stability as
RGB values may be indefinite for up to 100ms.

■I²C Communication Protocol

Communication method	I²C
Master/Slave	Slave
Transmission speed	100 kbps (Standard mode(*1))
Slave Address	40 h (Write: 80 h, Read: 81 h)
Clock Stretching	Yes (maximum clock stretch time: 1 ms)

*1: Reserved addresses (general call addresses, etc.) are not supported.

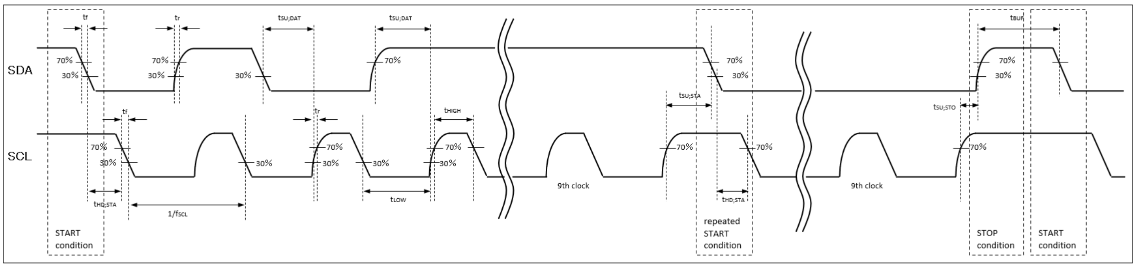
*Slave Address

bit	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
	Add[6]	Add[5]	Add[4]	Add[3]	Add[2]	Add[1]	Add[0]	R/W
Value	1	0	0	0	0	0	0	1/0

When writing: Set the LSB of the slave address to "0" to 80h (1000 0000b).

When reading: Set the LSB of the slave address to "1" to 81h (1000 0001b).

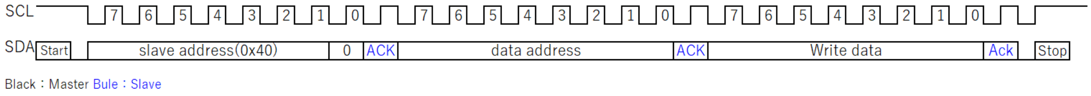
Defining I^2C Bus Timing



Characteristics of SDA and SCL Bus Lines

symbol	parameter	Min	Max	unit
f_{SCL}	SCL clock frequency	-	100	kHz
$t_{HD;STA}$	hold time (repeated) START condition	4.0	-	μs
t_{LOW}	LOW period of the SCL clock	4.7	-	μs
t_{HIGH}	HIGH period of the SCL clock	4.0	-	μs
$t_{SU;STA}$	set-up time for a repeated START condition	4.7	-	μs
$t_{SU;DAT}$	data set-up time	250	-	ns
t_r	rise time of both SDA and SCL signals	-	1000	ns
t_f	fall time of both SDA and SCL signals	-	300	ns
$t_{SU;STO}$	set-up time for STOP condition	4.0	-	μs
t_{BUF}	bus-free time between a STOP and START conditions	10.0	-	μs

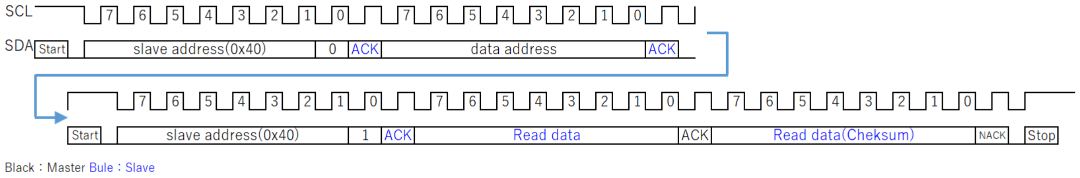
(1) Write



1. Operation is started by detecting the START condition.
2. The mode is switched to Write mode by receiving data with the Write bit ("0") added to the slave address (bits 7 to 1).
3. Set the received Write data to the received data address.

   (In the case of multiple consecutive Write bytes, when Write data is received in succession, Write data is set in sequence with the received data address at the top.)
4. The write operation is terminated upon detection of a STOP condition.

(2) Read



1. Operation is started by detecting the START condition.
2. The mode is switched to Write mode by receiving data with the Write bit ("0") added to the slave address (bits 7 to 1).
3. The register to receive and read the data address is specified.
4. The mode is switched to Read mode by detecting a repeated START condition and receiving the slave address (bit 7 to 1) plus the Read bit ("1").
5. Outputs 1 byte of data at the address specified by the data address as Read data.

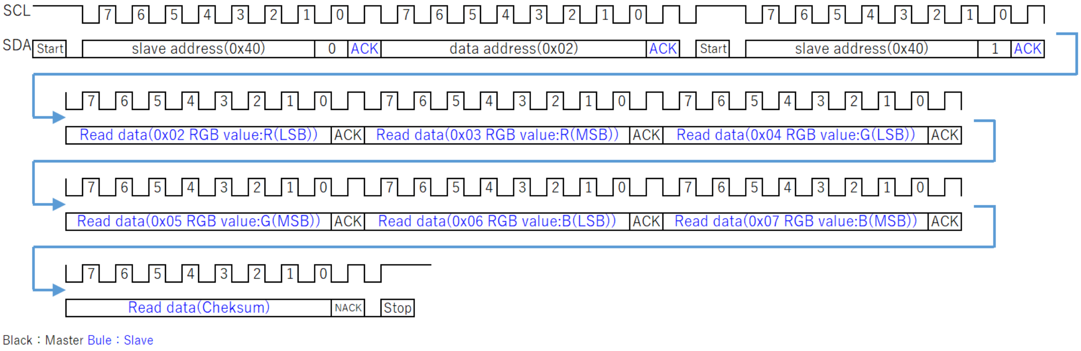
   *When 0x02 is specified for the data address, 6 bytes of data from 0x02 to 0x07 are output one byte at a time in sequence as Read data until NACK is detected.

   *Multiple data blocks (described in Chapter 12) cannot be read in a single Read message.
6. After Read data is output, the checksum is output.

   *Checksum is output only when the first address of each data block is specified in the data address.
7. Read operation is terminated upon detection of Stop condition.

   *If the read operation is continued, the value that can be read is indefinite.

*The following is an example of reading the 6 bytes from 0x02 to 0x07 and the checksum.



(3) Checksum

The calculated checksum is output as the final byte of the transmitted data using the following calculation method.

[Calculation Method]

Initial value: 0xFF   Formula: XOR of all Read data

[Example calculations]

An example of reading 6 bytes of RGB values is shown below.

Read data:

data address	0x02 RGB value :R (LSB)	0x03 RGB value :R (MSB)	0x04 RGB value :G (LSB)	0x05 RGB value :G (MSB)	0x06 RGB value :B (LSB)	0x07 RGB value :B (MSB)
value	0xAD	0x01	0x23	0x02	0xDE	0x03

Checksum:

Checksum = 0xFF(Initial value) XOR 0xAD XOR 0x01 XOR 0x23 XOR 0x02 XOR 0xDE XOR 0x03

= 0xAF

■I²C data address

The following are data address assignments and precautions for I²C communication.

<table>
<tr><th>data address (*1)</th><th>data block</th><th>summary</th><th>R/W (*2) (*4)</th><th>initial value (*3)</th><th>remarks</th></tr>
<tr><td>0x00</td><td>Protection features</td><td>Write Protect</td><td>R/W</td><td>0x5A</td><td>Permit/Prohibit writing to writable data addresses (*5)
0x5A:Write Protect Disabled
Other than 0x5A: Write Protect enabled</td></tr>
<tr><td>0x01</td><td>setup</td><td>Average number of times</td><td>R/W</td><td>0x14</td><td>Average number of RGB values to be output (*6)
LSB: 1, Unit: Times, Range: 1~50 (*7)</td></tr>
<tr><td>0x02</td><td rowspan="6">RGB value</td><td>RGB value : R (LSB)</td><td>Read Only</td><td>0x00</td><td rowspan="6">RGB value(*8)
LSB:3.3/1024 Unit: V Range:0~1023

RGB value recovery method
<table>
<tr><td>bit</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td>data</td><td colspan="6">0</td><td colspan="10">Effective data (0 to 1023)</td></tr>
<tr><td>RGB value: R</td><td colspan="8">0x03
RGB value : R(MSB)</td><td colspan="8">0x02
RGB value : R(LSB)</td></tr>
<tr><td>RGB value: G</td><td colspan="8">0x05
RGB value : G(MSB)</td><td colspan="8">0x04
RGB value: G(LSB)</td></tr>
<tr><td>RGB value: B</td><td colspan="8">0x07
RGB value: B(MSB)</td><td colspan="8">0x06
RGB value : B(LSB)</td></tr>
</table></td></tr>
<tr><td>0x03</td><td>RGB value : R (MSB)</td><td>Read Only</td><td>0x00</td></tr>
<tr><td>0x04</td><td>RGB value : G (LSB)</td><td>Read Only</td><td>0x00</td></tr>
<tr><td>0x05</td><td>RGB value : G (MSB)</td><td>Read Only</td><td>0x00</td></tr>
<tr><td>0x06</td><td>RGB value : B (LSB)</td><td>Read Only</td><td>0x00</td></tr>
<tr><td>0x07</td><td>RGB value : B (MSB)</td><td>Read Only</td><td>0x00</td></tr>
</table>

*1 : Do not access any data address other than those defined above.
It may respond NACK.
*2 : Do not make a write request to a Read Only data address.
It may respond NACK.
*3 : Value after power-on or soft reset.
*4 : It may take up to 10ms to reflect the value that has been written.
Please read and check if the values have been reflected.
*5 : When write protect is enabled, do not make write requests to writable addresses.
When write protect is enabled, writes to addresses other than data address 0x00 are not allowed.
It may respond NACK.
*6 : If the value of the average number of times is changed, the RGB value :R (LSB) to RGB value :B (MSB) may be indefinite for up to 100ms.
*7 : If a value outside the range is written, the ACK response is given but the value is not reflected.
*8 : When reading RGB value: R (LSB) to RGB value: B (MSB), read 6 bytes in one message.
If Read is not done in one telegram, data concurrency cannot be guaranteed.

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