Illuminance sensor investigation (electronic work) [Which one should I use?]

- Understand the basic specifications and programming of the illuminance sensor
- Practical data when used with ESP32

Use of sensors posted on this channel

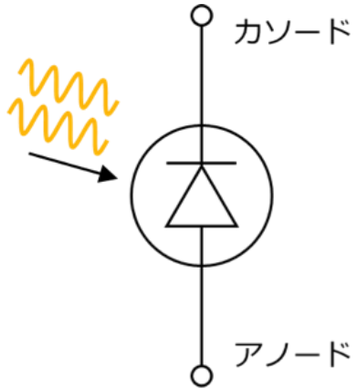
No	Sensor	Post name	URL
1	LED (Resistance value calculation)	If you want to start electronic work, start with this "L blinking"	https://hobby-it.com/smartremo2/
2	Infrared receiving sensor	Smart remote controller Electronic work (Infrared receiving sensor edition)	https://hobby-it.com/smartremo3/
3	Ir transmission LED (transistor)	Smart remote controller Electronic work (Ir transmission LED)	https://hobby-it.com/smartremo4/
4	Temperature sensor	Temperature sensor survey (electronic work) [1st place?]	https://hobby-it.com/temp-survey
5	Humidity sensor	Humidity sensor survey (electronic work) [1st place?]	https://hobby-it.com/humi-survey
6	Motion sensor	Motion sensor survey (electronic work) [1st place?]	https://hobby-it.com/motion-survey
7	Light sensor	Illuminance sensor investigation (electronic work) [Which one should I use?]	https://hobby-it.com/illum-survey
8	Camera [ESP32 & OV2640]	Save image to GoogleDrive[API]	https://hobby-it.com/save-jpeg-image-with-gdriveapi-1/
9		Save image to GoogleDrive[GAS]	https://hobby-it.com/save-jpeg-image-gdrivegas-1/
10	Camera [M5Stack TimerCamera]	Watch videos on your smartphone	https://hobby-it.com/m5timer_webcam
11		Post image to LINE with ESP32	https://hobby-it.com/m5timer_line
12		Saves images to Google Drive at regular and scheduled time	https://hobby-it.com/m5timer_gdrive
13		Add Camera to Refrigerator (Saved on GoogleDrive)	https://hobby-it.com/m5timer_refrigerator

table of contents

1-1. Photodiode

《Reference URL》
https://optipedia.info/laser/fiberlaser/photodiod/
https://www.analog.com/jp/analog-dialogue/raqs/raq-issue-108.html

● Photodiode mechanism



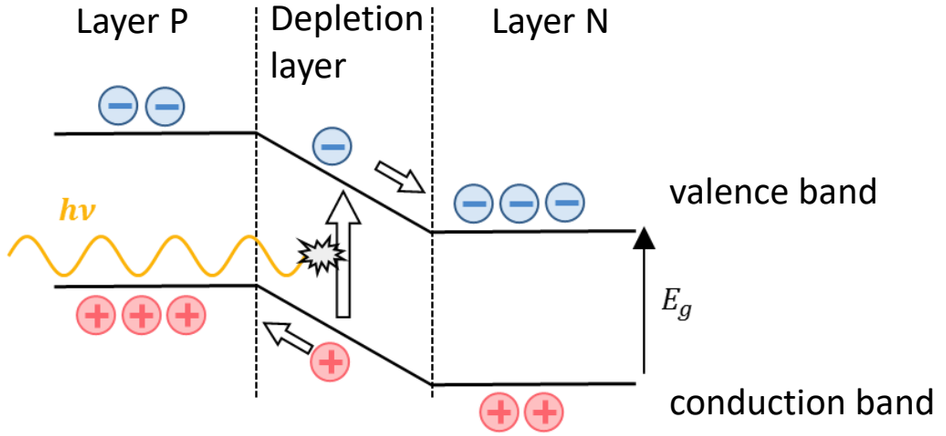
For more details

By interacting with light, matter can absorb light energy (photons) and release it as electrical energy (electrons). This is called the **photoelectric effect.**
When the photoelectric effect occurs in a semiconductor, a phenomenon called the photovoltaic effect occurs, in which a potential difference occurs at the junction. Photodiodes use these effects to detect light.

● LED can also generate power

LEDs have the same principle as photodiodes, and current flows when exposed to light.
Electricity can also be converted to light with a reverse bias, so it is normally used to emit light.

● Basic structure of a photodiode



E_g: bandgap energy
$h\nu$: light energy

When the energy of the incident light is greater than the bandgap energy of the semiconductor, electrons in the semiconductor crystal are excited and pulled up from the valence band to the conduction band.

At this time, a positive charge (hole) is generated at the original position of the electron. These electrons and holes move to the N layer and P layer, respectively, due to the potential difference between the two layers.

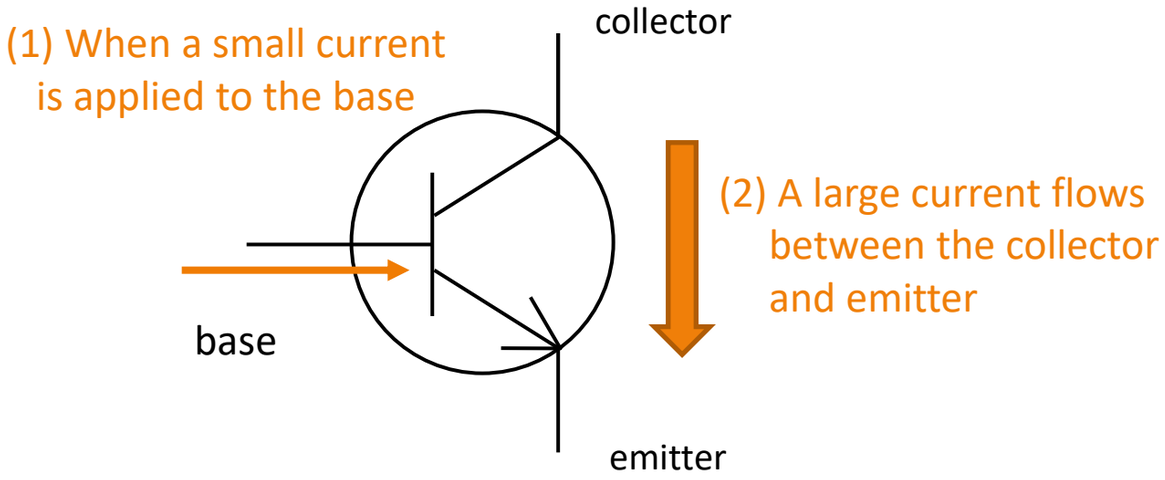
As a result, a current is generated, which can be extracted as a current signal by connecting an external circuit such as an amplifier to the photodiode, enabling light detection.

Since the materials used for photodiodes have wavelength-dependent quantum efficiency, it is necessary to select materials for each wavelength. Indium-gallium-arsenide (InGaAs) is suitable for the near-infrared region.

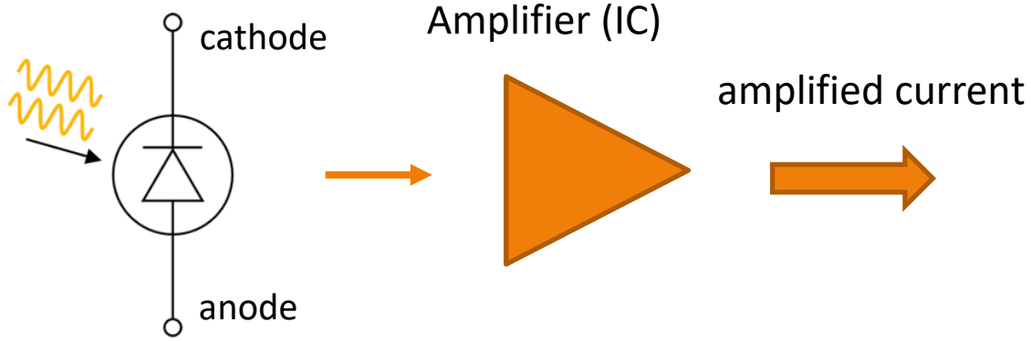
1-2. Phototransistor/Photo IC Diode

《Reference URL》
https://metoree.com/categories/phototransistor/
https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/photo_ic_diode_kpic9007j.pdf

● Operation of the transistor

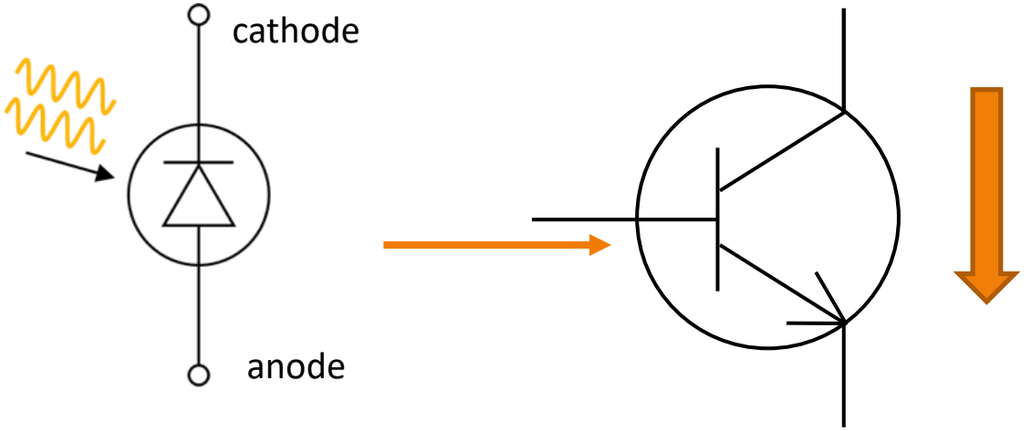


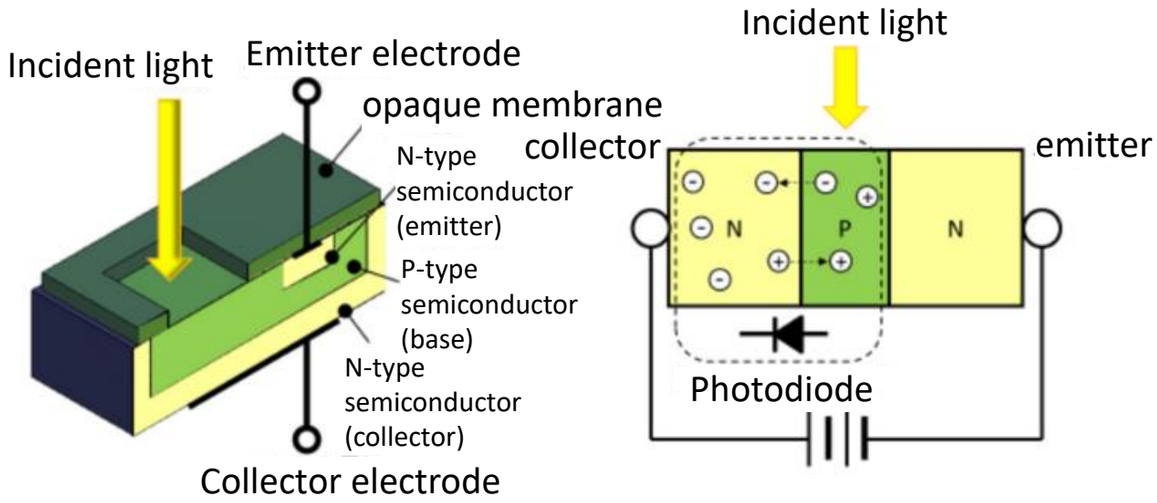
● Photo IC diode



● Phototransistor

"Photodiode" + "transistor" structure, amplifying the current extracted by the photodiode with a transistor





1-3. Approximate illuminance and brightness

《Reference URL》
https://www.engineeringtoolbox.com/light-level-rooms-d_708.html

Outdoor Light Levels

Condition	Illumination	
	(ftcd)	*(lux)*
Sunlight	10000	107527
Full Daylight	1000	10752
Overcast Day	100	1075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	0.1	1.08
Full Moon	0.01	0.108
Quarter Moon	0.001	0.0108
Starlight	0.0001	0.0011
Overcast Night	0.00001	0.0001

Indoor Light Levels

Activity	Illuminance *(lx, lumen/m^2)*
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Areas with traffic and corridors - stairways, escalators and travelators - lifts - storage spaces	100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, homes, theaters, archives, loading bays	150
Coffee break room, technical facilities, ball-mill areas, pulp plants, waiting rooms,	200
Easy office work	250
Class rooms	300
Normal office work, PC work, study library, groceries, show rooms, laboratories, check-out areas, kitchens, auditoriums	500
Supermarkets, mechanical workshops, office landscapes	750
Normal drawing work, detailed mechanical workshops, operation theaters	1000
Detailed drawing work, very detailed mechanical works, electronic workshops, testing and adjustments	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Brightness around 100 lux in indoor environment

2-1. Ambient light sensor to investigate

Selection criteria (IT Taro survey)
・3.3V/5V compatible
・In order from the same type of cheap item
(Do not select if the price of the next item is more than double)

NO	項目	manufacturer	model number	Image	URL	Price	Ope Vol	peak waveler	Note
1	Illuminance sensor (phototransistor) NJL7302L-F3	Nisshinbo Micro Device	NJL7302L-F3		https://akizukidenshi.com/catalog/g/gI-08910/	45	～15V	550 nm	
2	Illuminance sensor (phototransistor) NJL7302L-F5	Nisshinbo Micro Device	NJL7302L-F5		https://akizukidenshi.com/catalog/g/gI-08700/	50	～15V	550 nm	
3	Illuminance sensor (phototransistor) NJL7502L (2 pieces)	Nisshinbo Micro Device	NJL7502L		https://akizukidenshi.com/catalog/g/gI-02325/	50	～70V	560 nm	Must be purchased as a pack of 2 for 100 yen
4	Photo IC diode S13948-01SB	Hamamatsu Photonics	S13948-01SB		https://akizukidenshi.com/catalog/g/gI-13874/	100	～12V	560 nm	
5	Grove-Light Sensor v1.2	Seeed Studio	101020132		https://jp.seeedstudio.com/Grove-Light-Sensor-v1-2-LS06-S-phototransistor.html	269	3-5 V	540 nm	Buy at a nearby store, not online
Total						**514**			

Cadmium sulfide (CdS) cells are cheap and easy to use (light can be treated as resistance).
However, cadmium seems to be a regulated element under the RoHS Directive (Rose Directive: European Union (EU) Directive on Restrictions on the Use of Certain Hazardous Substances in Electronic and Electrical Equipment).
It seems that the environmental load is large, so it was excluded from the selection.

2-2. Illuminance sensor to be investigated (specified)

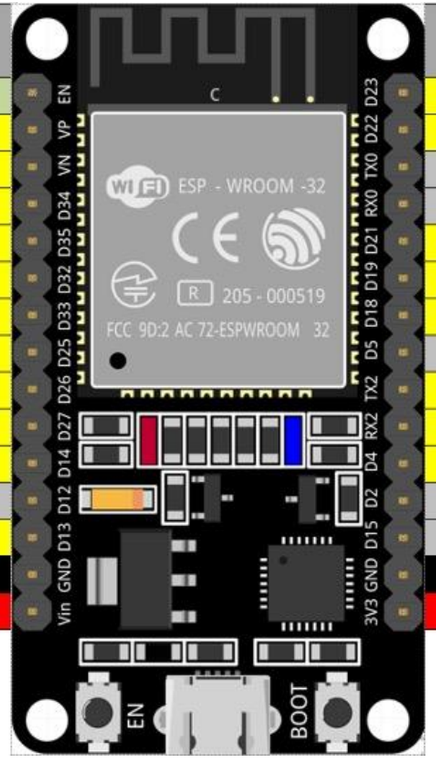
The product types can be classified into the following three types: "photodiodes", "photo IC diodes", and "modularization".

Type	Content	Price Range	How to Use	Note
Phototransistor [NJL7302L-F3/F5, NJL7502L] 	A product that integrates a photodiode and a transistor	inexpensive	Since the current changes when exposed to light, the change is measured (The change in current is measured by measuring the voltage across the resistor)	
Photo IC diode [S13948] 	A product that integrates a photodiode and a current amplifier	somewhat inexpensive		
Modularization [Grove-Light Sensor] 	Products in which elements required for substrates are integrated	expensive	Measures illuminance from changes in output voltage	

3-1. ESP32 port

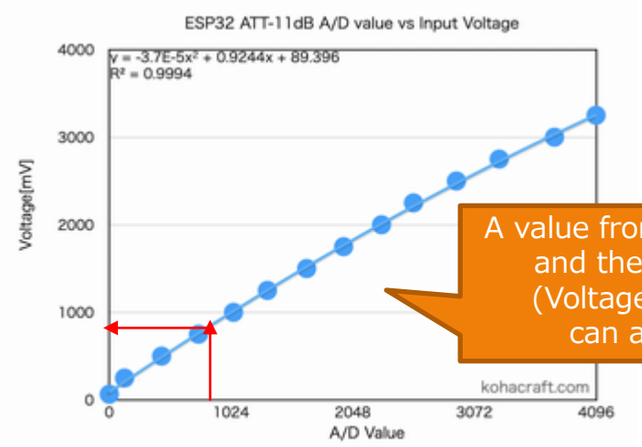
- ESP32 port configuration

Touch	SPI/ DAC	Analog (ADC)		IO
				EN
		1-0	A0	GPI 36(VP)
		1-3	A3	GPI 39(VN)
		1-6	A6	GPI 34
		1-7	A7	GPI 35
T9		1-4	A4	GPIO32
T8		1-5	A5	GPIO33
	DAC_1	2-8	A18	GPIO25
	DAC_2	2-9	A19	GPIO26
T7		2-7	A17	GPIO27
T6	HSPICLK	2-6	A16	GPIO14
T5	HSPIQ	2-5	A15	GPIO12
T4	HSPID	2-4	A14	GPIO13
				GND
				5V



IO	Analog (ADC)		SPI/ Serial	I2C/ Touch
GPIO23			VSPID	
GPIO22			VSPIWP	SCL
GPIO1			TXD0	
GPIO3			RXD0	
GPIO21			VSPIHD	SDA
GPIO19			VSPIQ	
GPIO18			VSPICLK	
GPIO5			VSPICS0	
GPIO17			TXD2	
GPIO16			RXD2	
GPIO4	A10	2-0	HSPIHD	T0
GPIO2	A12	2-2	HSPIWP	T2
GPIO15	A13	2-3	HSPICS0	T3
GND				
3.3V				

- ADC terminal
  - Two ADC circuits are installed.
  - Attenuation of 11dB is set as standard, so measurement from 0 to 3.3V is possible.
  - The resolution is 9 to 12 bits. Since it is 12bit by default, it is output in 0 to 4095.
    (It is also possible to output the voltage-converted value. This time, we will use this function.)
  - Wi-Fi is not available when using ADC2



https://kohacraft.com/archives/202202091047.html

3-2. ESP32 input terminal

● M5Stack Official　ESP32
https://www.espressif.com/sites/default/files/documentation/esp32-pico-d4_datasheet_en.pdf

5. Electrical Characteristics

5.1 Absolute Maximum Ratings

Stresses beyond the absolute maximum ratings listed in the table below may cause permanent damage to the device. These are stress ratings only, and do not refer to the functional operation of the device that should follow the recommended operating conditions.

Table 11: Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Unit
VDDA, VDD3P3, VDD3P3_RTC, VDD3P3_CPU, VDD_SDIO	Voltage applied to power supply pins per power domain	–0.3	3.6	V
I_{output} *	Cumulative IO output current	-	1,200	mA
T_{store}	Storage temperature	–40	150	°C

* The chip worked properly after a 24-hour test in ambient temperature at 25 °C, and the IOs in three domains (VDD3P3_RTC, VDD3P3_CPU, VDD_SDIO) output high logic level to ground.

5.3 DC Characteristics (3.3 V, 25 °C)

Table 13: DC Characteristics (3.3 V, 25 °C)

Symbol	Parameter		Min	Typ	Max	Unit
C_{IN}	Pin capacitance		-	2	-	pF
V_{IH}	High-level input voltage		0.75×VDD[1]	-	VDD[1]+0.3	V
V_{IL}	Low-level input voltage		–0.3	-	0.25×VDD[1]	V
I_{IH}	High-level input current		-	-	50	nA
I_{IL}	Low-level input current		-	-	50	nA
V_{OH}	High-level output voltage		0.8×VDD[1]	-	-	V
V_{OL}	Low-level output voltage		-	-	0.1×VDD[1]	V
I_{OH}	High-level source current (VDD[1] = 3.3 V, V_{OH} >= 2.64 V, output drive strength set to the maximum)	VDD3P3_CPU power domain [1, 2]	-	40	-	mA
		VDD3P3_RTC power domain [1, 2]	-	40	-	mA
		VDD_SDIO power domain [1, 3]	-	20	-	mA
I_{OL}	Low-level sink current (VDD[1] = 3.3 V, V_{OL} = 0.495 V, output drive strength set to the maximum)		-	28	-	mA
R_{PU}	Pull-up resistor		-	45	-	kΩ
R_{PD}	Pull-down resistor		-	45	-	kΩ
V_{IL_nRST}	Low-level input voltage of CHIP_PU to power off the chip		-	-	0.6	V

Notes:

1. Please see Table IO_MUX for IO's power domain. VDD is the I/O voltage for a particular power domain of pins.
2. For VDD3P3_CPU and VDD3P3_RTC power domain, per-pin current sourced in the same domain is gradually reduced from around 40 mA to around 29 mA, V_{OH}>=2.64 V, as the number of current-source pins increases.
3. For VDD_SDIO power domain, per-pin current sourced in the same domain is gradually reduced from around 30 mA to around 10 mA, V_{OH}>=2.64 V, as the number of current-source pins increases.

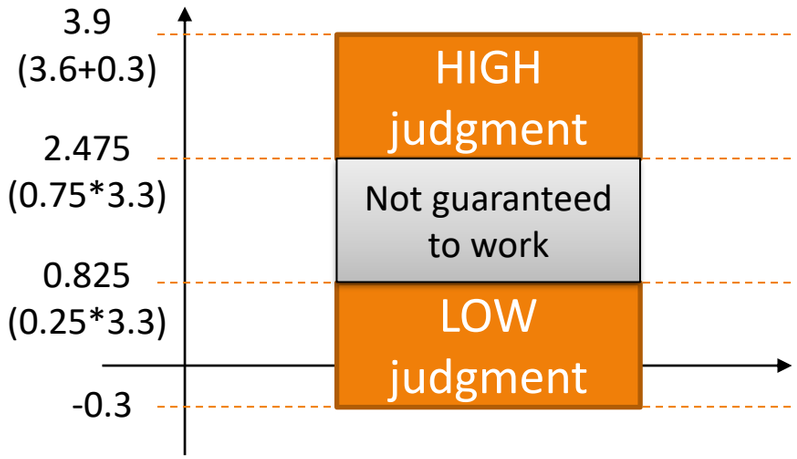
IO-Pin
Maximum input voltage

3.9（3.6+0.3）

IO-Pin
Output Current

40mA

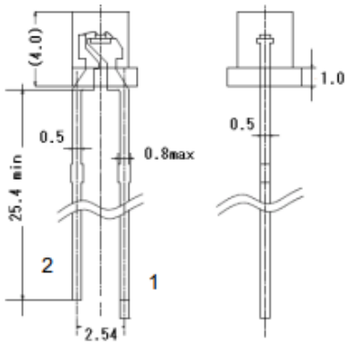
● Input HIGH/LOW judgment of ESP32



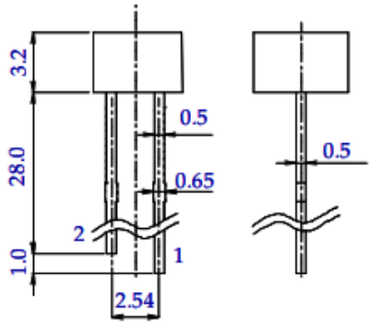
Since the input is up to MAX3.9V,
it is impossible to input a 5V signal.

4-1.NJL7302L-F3/F5

《Reference URL》
https://www.nisshinbo-microdevices.co.jp/ja/pdf/datasheet/NJL7302L-F3_NJL7302L-F5_J.pdf



1 : Collector
2 : Emitter



NJL7302L-F3

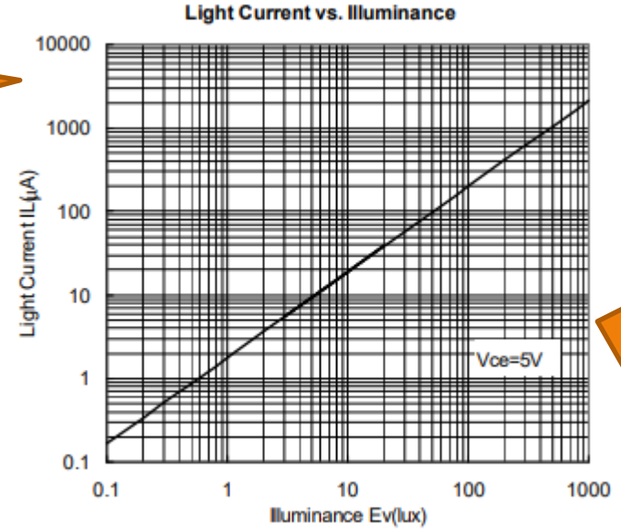
NJL7302L-F5

半値角	$\Theta_{1/2}$	NJL7302L-F3	—	±55	—	deg.
		NJL7302L-F5	—	±45	—	

F3 has a wider half-value angle (grasp light with a wide angle)

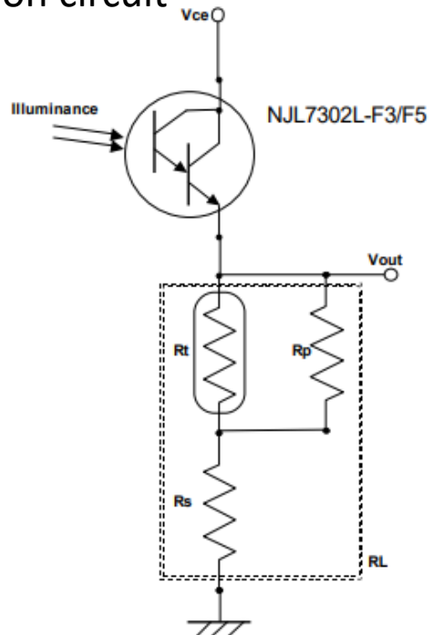
● Relationship between flowing current and illuminance

Max about 10mA



The current that flows changes depending on the brightness of the light
(Illuminance measurement using this current)

● Example of application circuit



Rt :NTC Thermistor NCP18 Series (muRata)
Rs:Chip Resistance MCR03 F Series (Rohm)
Rp:Chip Resistance MCR03 F Series (Rohm)

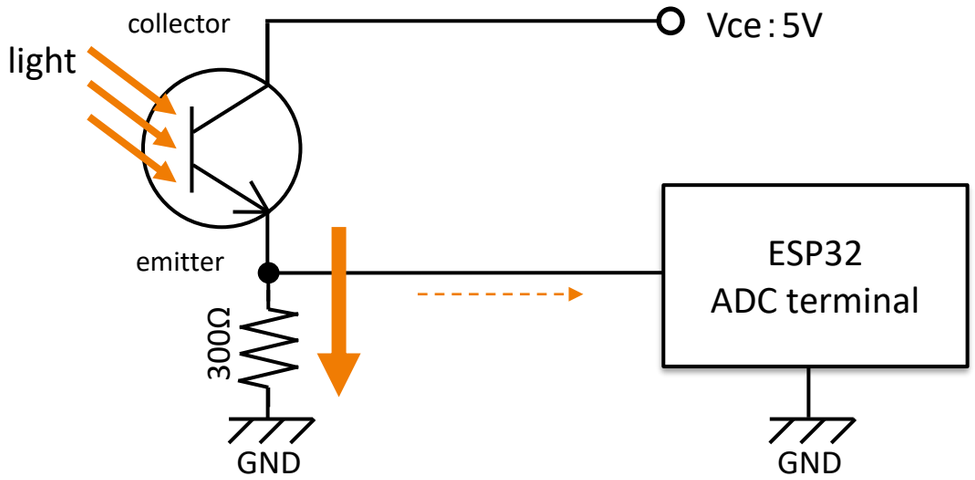
例
Condition : Vce=5V , Ev=5lux , Vout=1.0V

Rt	100kΩ
Rs	33kΩ
Rp	180kΩ

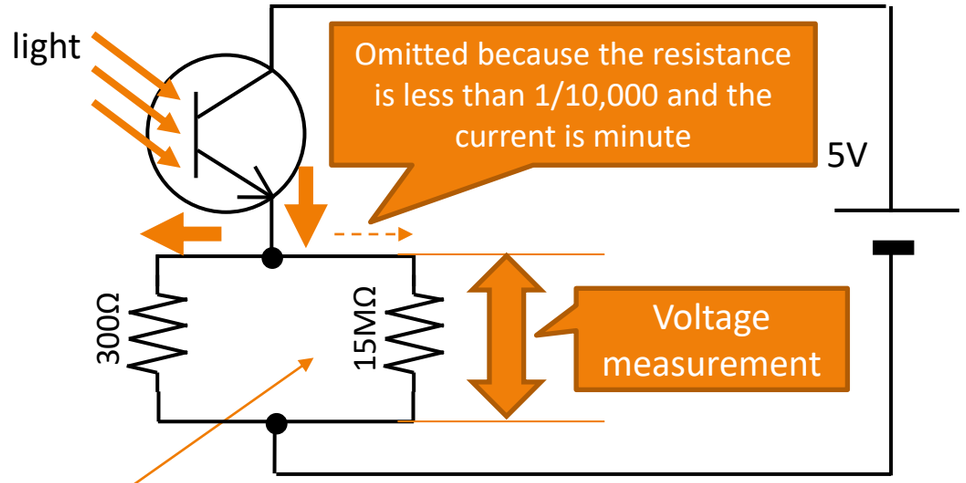
4-1.NJL7302L-F3/F5

《Reference URL》
https://www.nisshinbo-microdevices.co.jp/ja/pdf/datasheet/NJL7302L-F3_NJL7302L-F5_J.pdf
http://radiopench.blog96.fc2.com/blog-entry-1035.html

● Measurement circuit



● Measurement circuit (equivalent and easy to understand?)



ESP32 is connected in parallel to a resistor, voltage is measured with ADC, and current is acquired Ohm's law “I = V / R”

[Calculation of resistance value]
Photodiode: 0 to 10mA change
ESP32-ADC measurement: 0 to 3.3V (assume 3V)

Ohm's law R = V / I
= 3V / 0.01A(10mA) = 300Ω

10mA : Measures up to about 100,000 lux

ESP32 ADC input resistance 《Reference URL》

GPIO36 (ADC1 CH0) Att=−11dB			
V1(直接)	V2(1MΩ)	V3(+0.1uF)	Rin(MΩ)
1004	938	940	14.2
2001	1889	1889	16.9
3002	2790	2790	13.2

About 15 MΩ

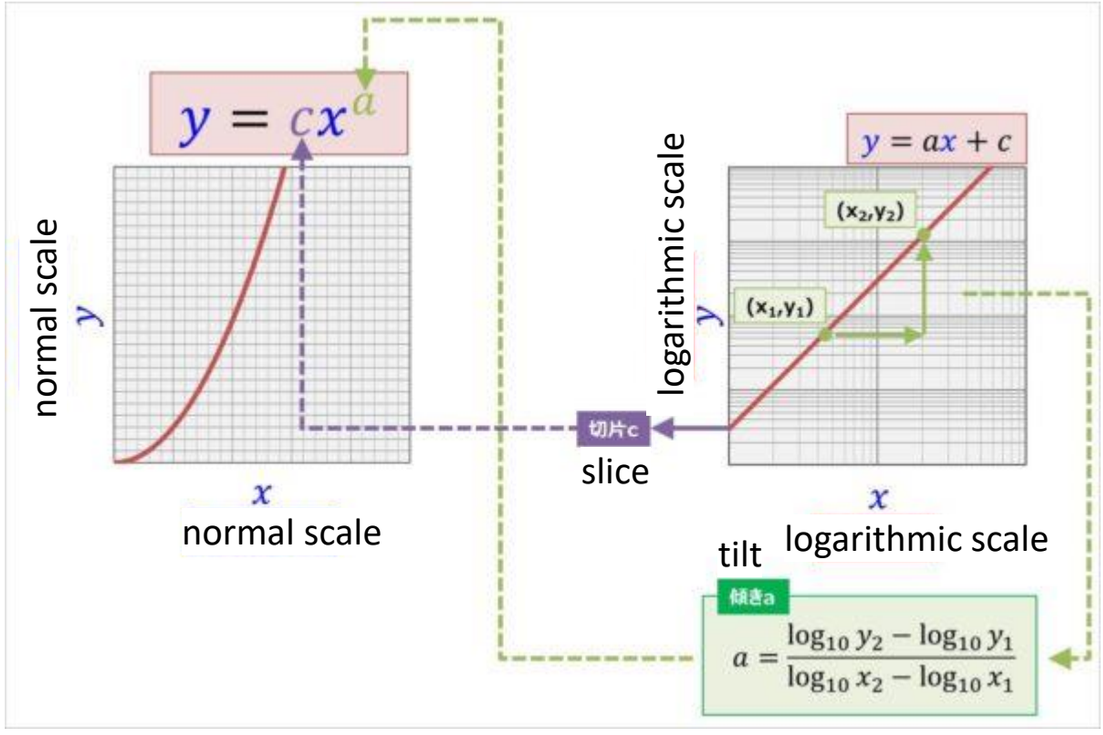
http://radiopench.blog96.fc2.com/blog-entry-1035.html

4-1.NJL7302L-F3/F5

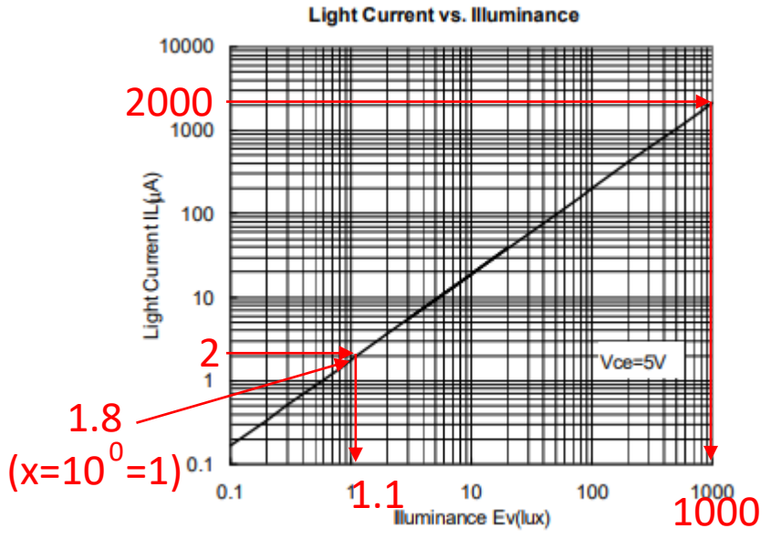
《Reference URL》
https://www.nisshinbo-microdevices.co.jp/ja/pdf/datasheet/NJL7302L-F3_NJL7302L-F5_J.pdf
https://detail-infomation.com/semi-log-plot-and-log-log-plot/
https://mathlandscape.com/log-log-graph/

● Relational expression of log-log graph

https://detail-infomation.com/semi-log-plot-and-log-log-plot/



● Relational expression between current and lux



Illuminance(Lux)

Get values visually from a graph

$$a = \frac{\log 2000 - \log 2}{\log 1000 - \log 1.1} = 1.01399 \qquad c = 1.8$$

$$y = 1.8\ x^{\,1.01399}$$

apply log to both sides

$$\log y = \log 1.8 \times 1.01399$$
$$= \log 1.8 + 1.01399 \log x$$

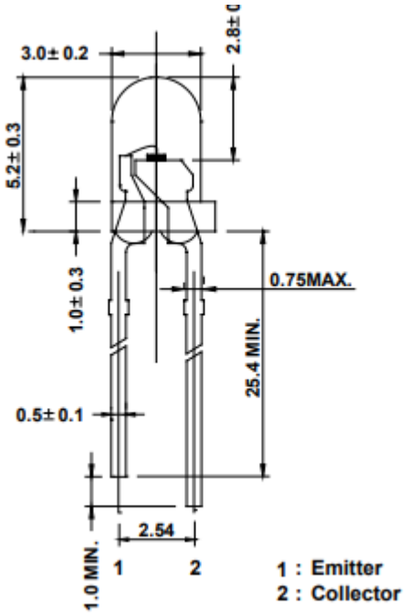
$$\log x = \frac{\log y - \log 1.8}{1.01399}$$

Lux conversion formula from current

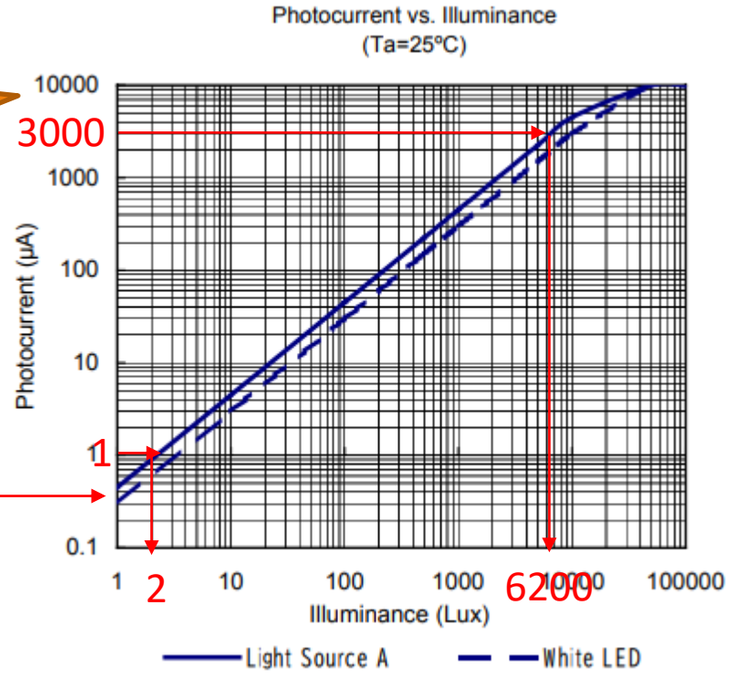
$$x = 10^{\frac{\log y - \log 1.8}{1.01399}}$$

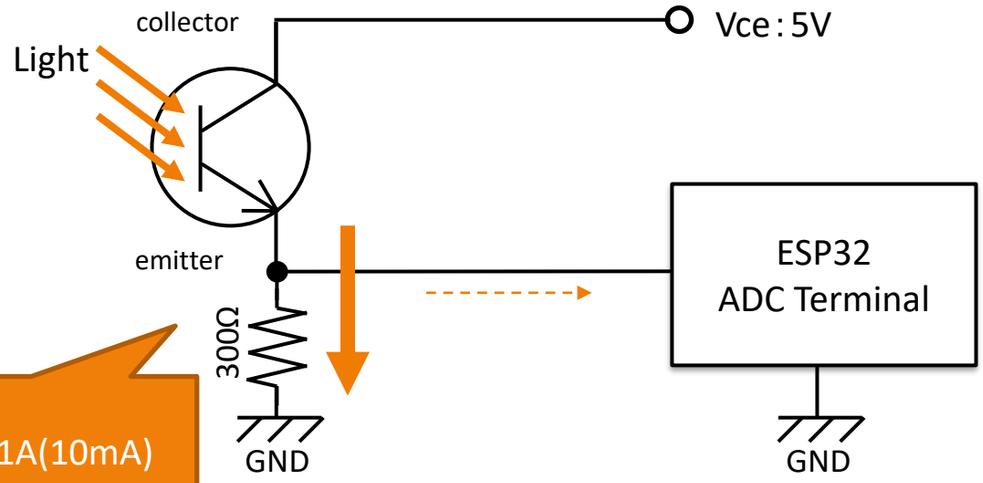
4-2. NJL7502L

《Reference URL》
https://www.nisshinbo-microdevices.co.jp/ja/pdf/datasheet/NJL7502L_J.pdf



Max about
10mA





$$a = \frac{\log 3000 - \log 1}{\log 6200 - \log 2} = 0.99592 \qquad c = 0.47$$

R = V / I
= 3V / 0.01A(10mA)
= 300Ω

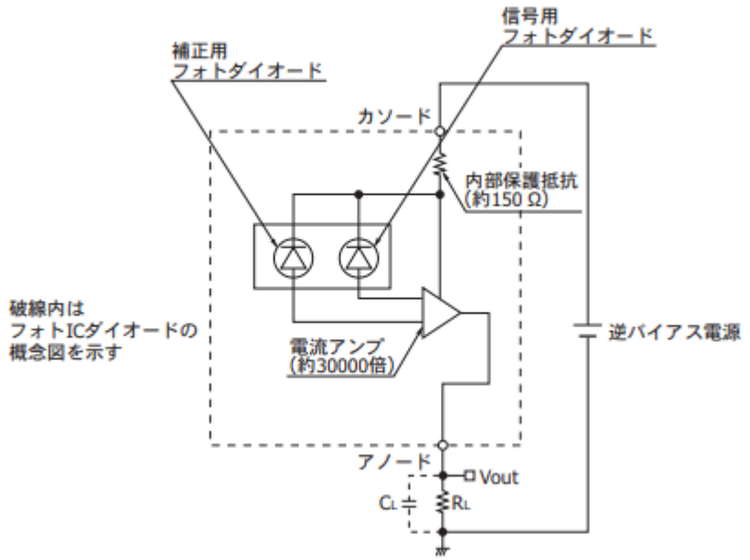
Lux conversion formula from current

$$x = 10^{\frac{\log y - \log 0.47}{0.99592}}$$

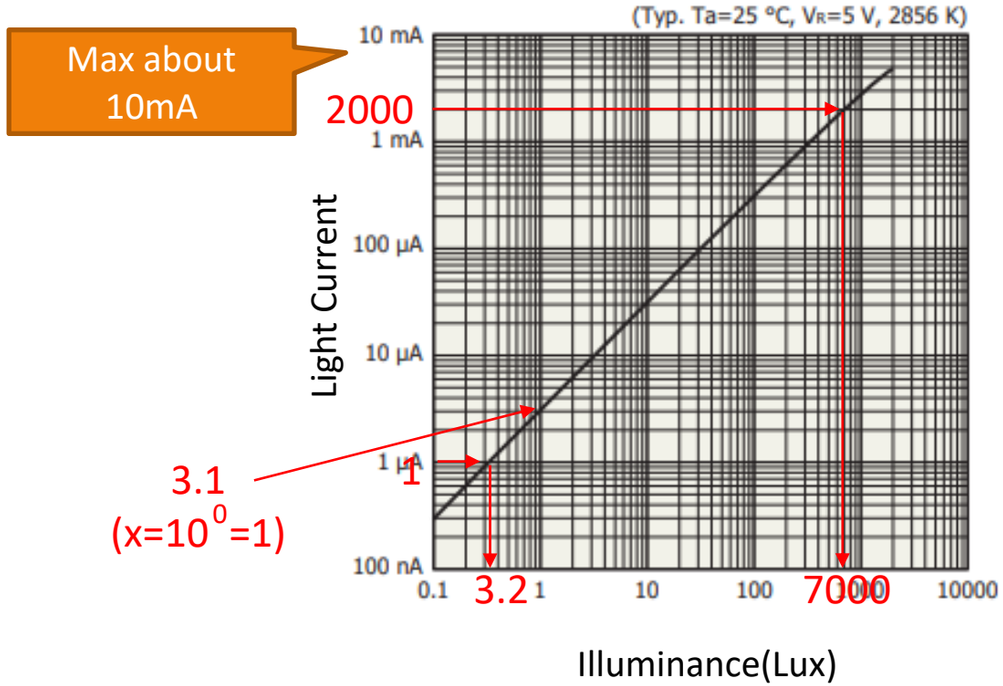
4-3. S13948

《Reference URL》
https://akizukidenshi.com/download/ds/hamamatsu/s13948-01sb.pdf

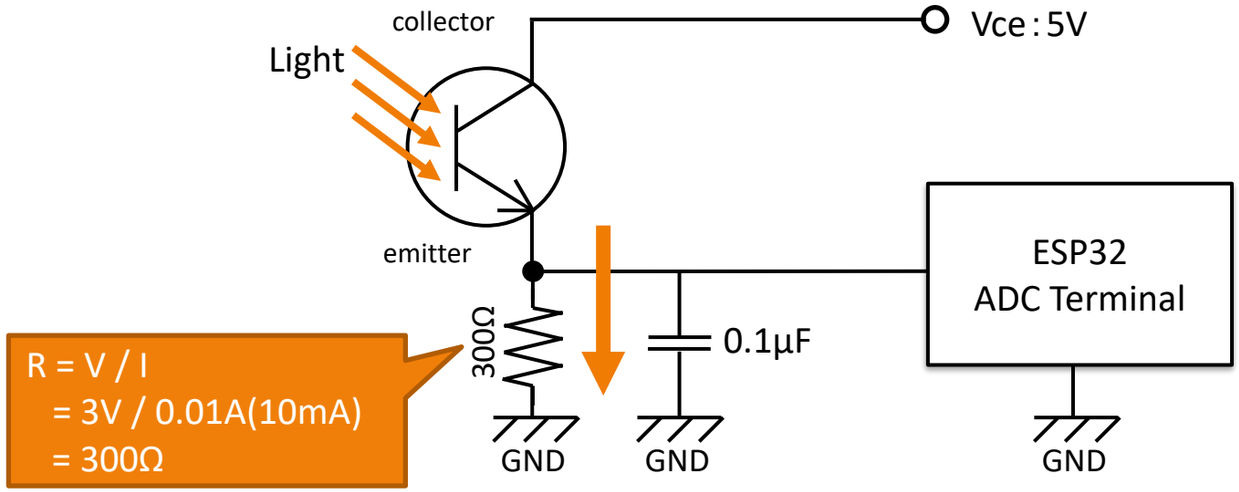
● Block Diagram



● Relational expression between current and lux



$$a = \frac{\log 2000 - \log 1}{\log 7000 - \log 3.2} = 0.98835 \qquad c = 3.1$$



R = V / I
= 3V / 0.01A(10mA)
= 300Ω

Lux conversion formula from current

$$x = 10^{\frac{\log y - \log 3.1}{0.98835}}$$

4-4. Grove-Light Sensor v1.2

《Reference URL》
https://wiki.seeedstudio.com/Grove-Light_Sensor

Seeeduino	Grove-Light Sensor
5V	Red
GND	Black
Not Conencted	White
A0	Yellow

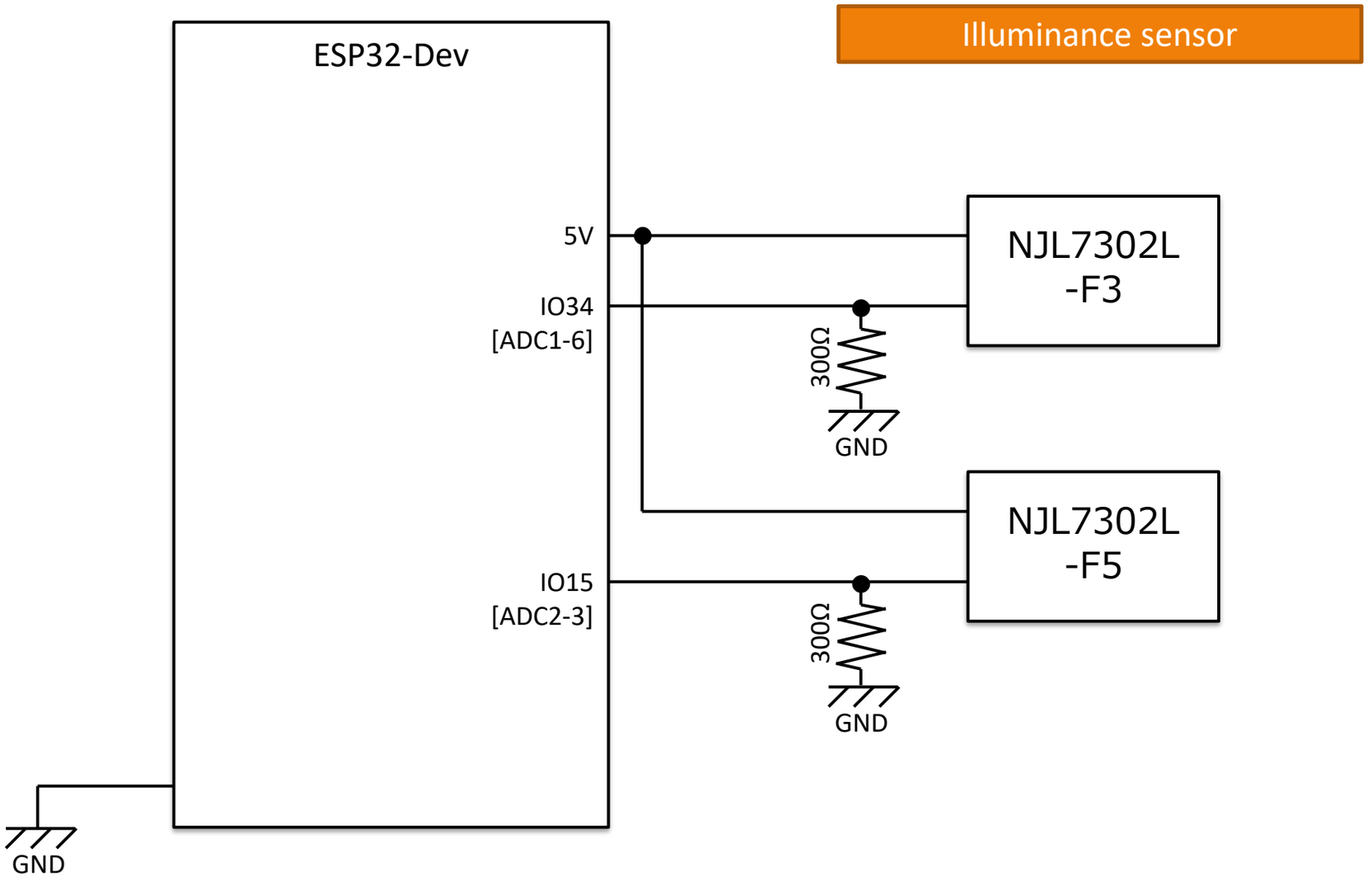
● Sample program

```
#include <Grove_LED_Bar.h>

Grove_LED_Bar bar(3, 2, 0);  // Clock pin, Data pin, Orientation

void setup()
{
  // nothing to initialize
  bar.begin();
  bar.setGreenToRed(true);
}

void loop()
{

  int value = analogRead(A0);
  value = map(value, 0, 800, 0, 10);

  bar.setLevel(value);
  delay(100);
}
```

Specifications that display brightness with 10 levels of LEDs according to the output voltage
No relationship graph between output voltage (current) and lux
Check how much lux the 10 steps represent

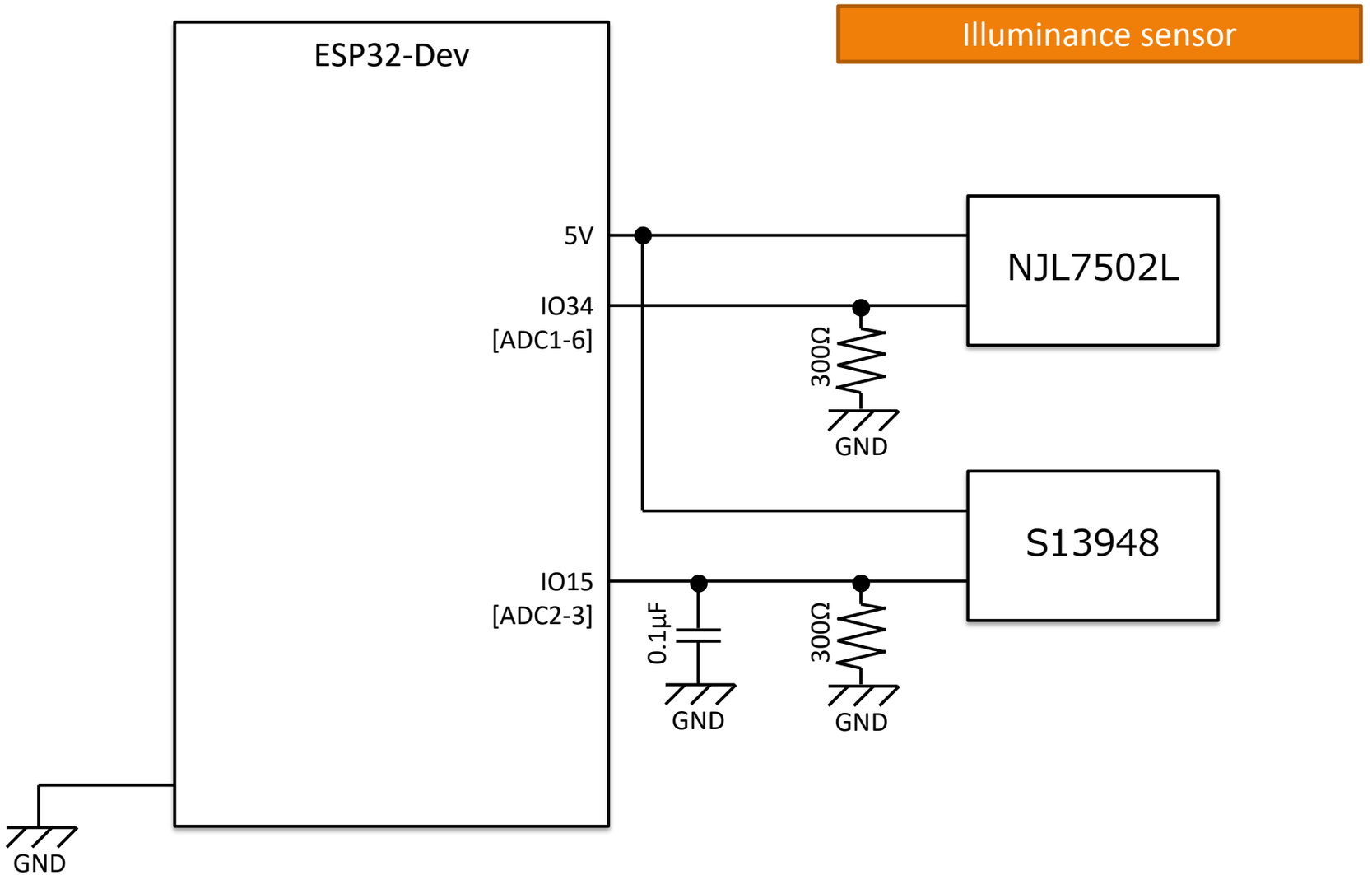
5-1. circuit 1

Attach sensors to two ADCs of ESP32 and measure voltage



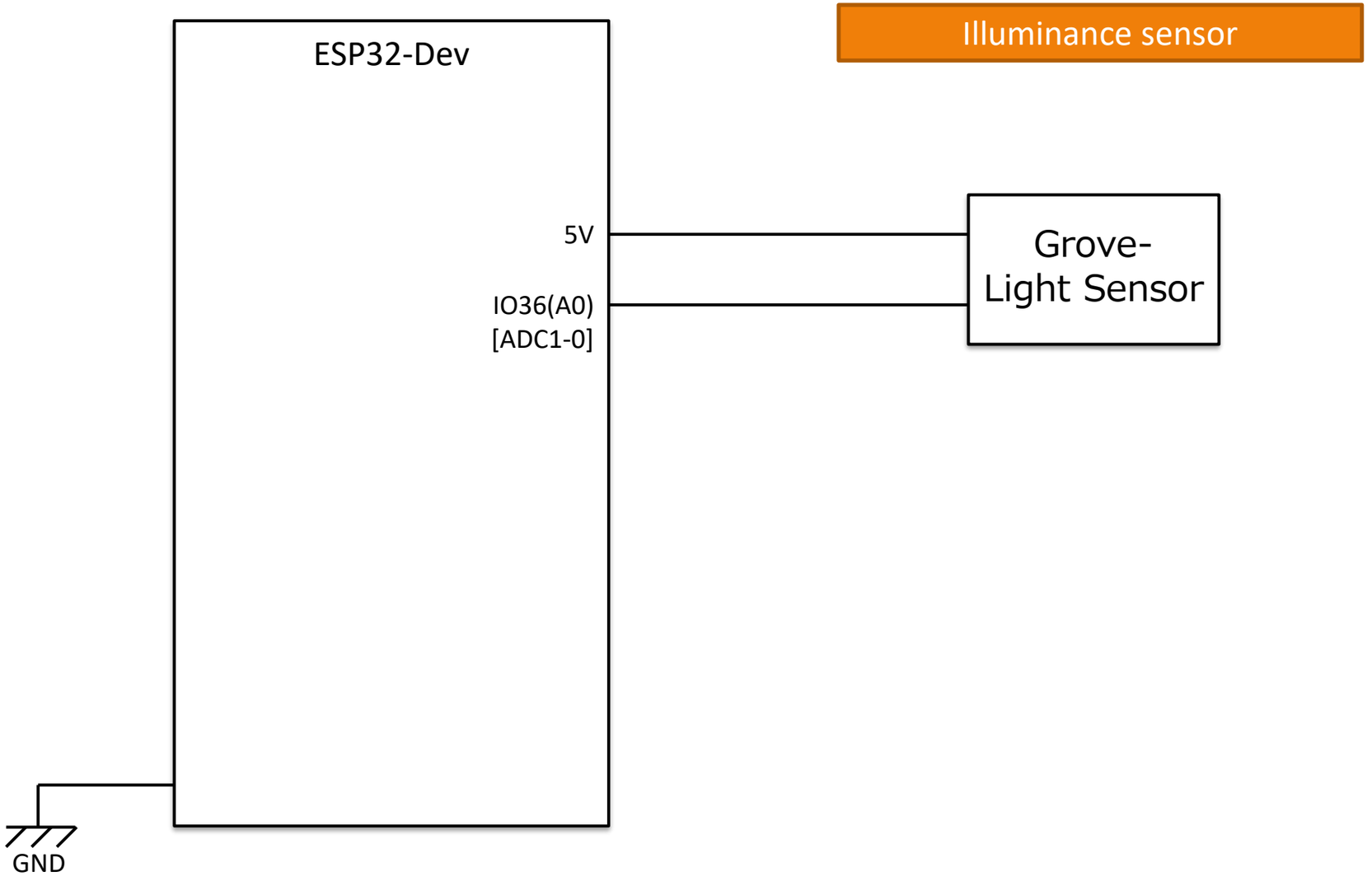
5-2. circuit 2

Attach sensors to two ADCs of ESP32 and measure voltage



5-3. circuit 3

Attach a sensor to the ESP32's ADC and perform a voltage measurement



6. Program

All the programs used for the measurement are open to the public.
《Hobby-IT》 https://hobby-it.com/
(The URL is listed in the summary column.)

```
#define ADC1_PIN 34
#define ADC2_PIN 15

unsigned long loopCount = 0;

void setup() {
  // Serial monitor
  Serial.begin(115200);
  // ADC Setting
  //analogSetAttenuation(ADC_0db);  // ATT 0dB[Default 11db]
  //analogSetAttenuation(ADC_6db);  // ATT -6dB[Default 11db],
  //analogSetWidth(10);             // Resolution Default:12bit(0-4095)[9-12]
  pinMode(ADC1_PIN, ANALOG);
  pinMode(ADC2_PIN, ANALOG);
  // Display Serial monitor
  Serial.println("Setup completed!");
}

void loop() {
  // Sleep[5 sec]
  delay(5000);
  loopCount++;
  // ADC1[NJL7302L-F3]
  uint16_t analog1_adc = analogRead(ADC1_PIN);
  uint32_t analog1_mv = analogReadMilliVolts(ADC1_PIN);
  // Convert voltage to current (I=V/R) [micro A (* 1000)]
  double lightCur1 = (double)analog1_mv * 1000.0 / 300.0;
  // Convert current to lux
  double lightLux1 = pow(10, ((log10(lightCur1)-log10(1.8))/1.01399) );
  Serial.printf("[%ld] NJL7302L-F3 ADC=%d, mV=%d[mV], lightCur=%5.2f[A], lightLux=%6.1f[lux]\n", loopCount, analog1_adc, analog1_mv, lightCur1, lightLux1);
  // ADC2[NJL7302L-F5]
  uint16_t analog2_adc = analogRead(ADC2_PIN);
  uint32_t analog2_mv = analogReadMilliVolts(ADC2_PIN);
  // Convert voltage to current (I=V/R)
  double lightCur2 = (double)analog2_mv * 1000.0 / 300.0;
  // Convert current to lux
  double lightLux2 = pow(10, ((log10(lightCur2)-log10(1.8))/1.01399) );
  Serial.printf("[%ld] NJL7302L-F5 ADC=%d, mV=%d[mV], lightCur=%5.2f[A], lightLux=%6.1f[lux]\n", loopCount, analog2_adc, analog2_mv, lightCur2, lightLux2);
}
```

ADC port settings

Measured every 5 seconds

ADC measurement

Current calculation (I=V/R)

Lux calculation

Sensor 1 measurement

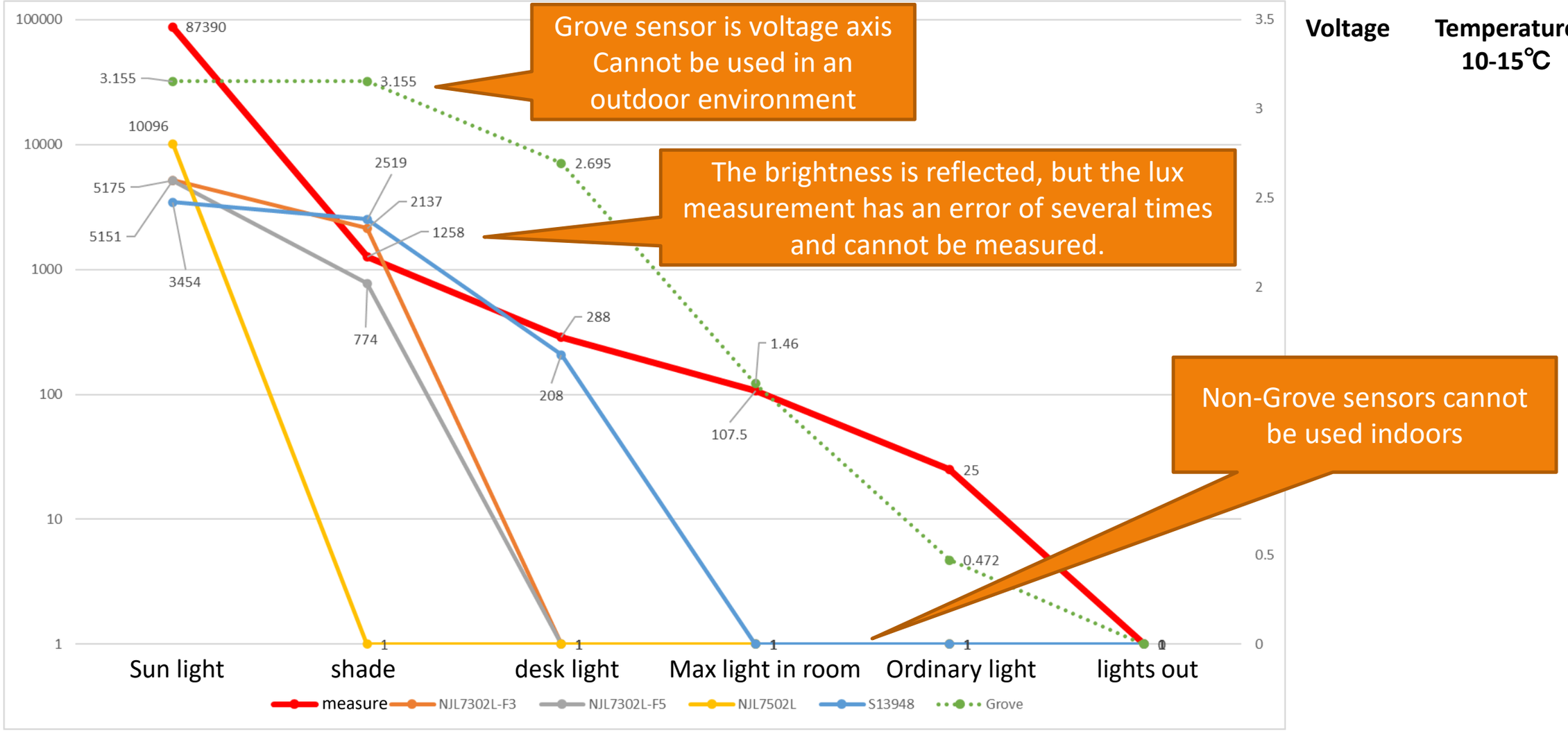
Sensor 2 measurement

7. Measuring instrument

Use the smartphone (app) illuminance meter as a measuring instrument.

8. Measurement result 1 (5V, 330Ω)

When using a 330 ohm resistor, it is used when measuring a large brightness.
(However, the Grove sensor has a built-in resistance and cannot be changed. It cannot measure more than 5000 lux and is for indoor environments.)
Voltage can be measured by reflecting brightness, but lux measurement cannot be measured
because there is a difference of several times.

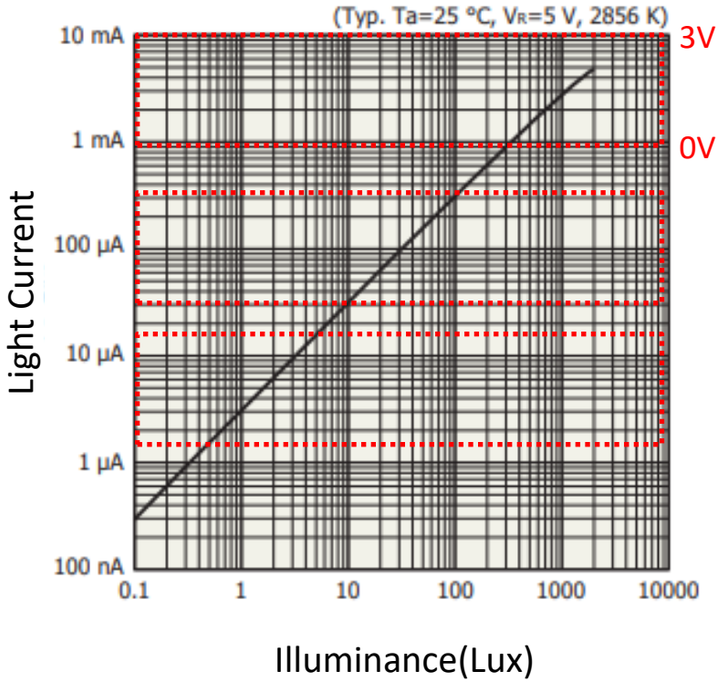


9-1. Review circuit and resistance value

The ESP32's ADC circuit cannot measure with high accuracy,
so the current that can be used to measure illuminance is limited.

It is necessary to use different resistance values depending on the application.

● Relational expression
between current and lux

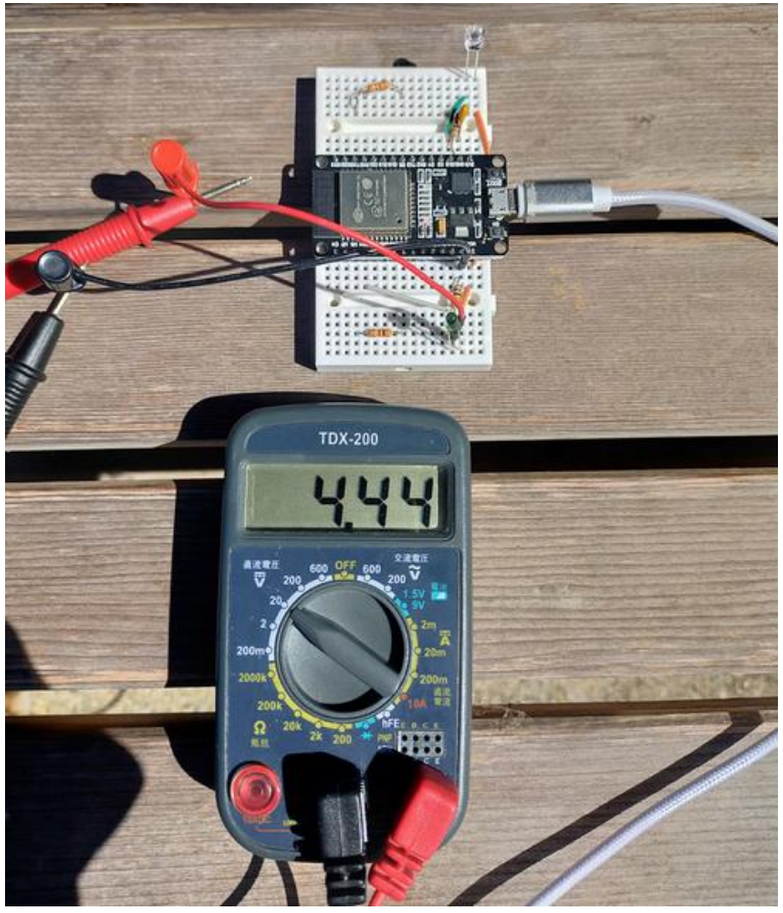


resistance	Current that can be measured	Illuminance that can be measured	Assumed use
300Ω	1mA ～ 10mA	300 lux ～ 10000 lux	Judgment of sunlight and shade
10kΩ	0.03mA ～ 0.33mA (30µA～330µA)	300 lux ～ 10000 lux	Judgment of indoor lighting (bright place)
200kΩ	0.001mA ～ 0.0166mA (1µA～16.6µA)	0.5 lux ～ 5 lux	Judgment of indoor lighting (dark place)

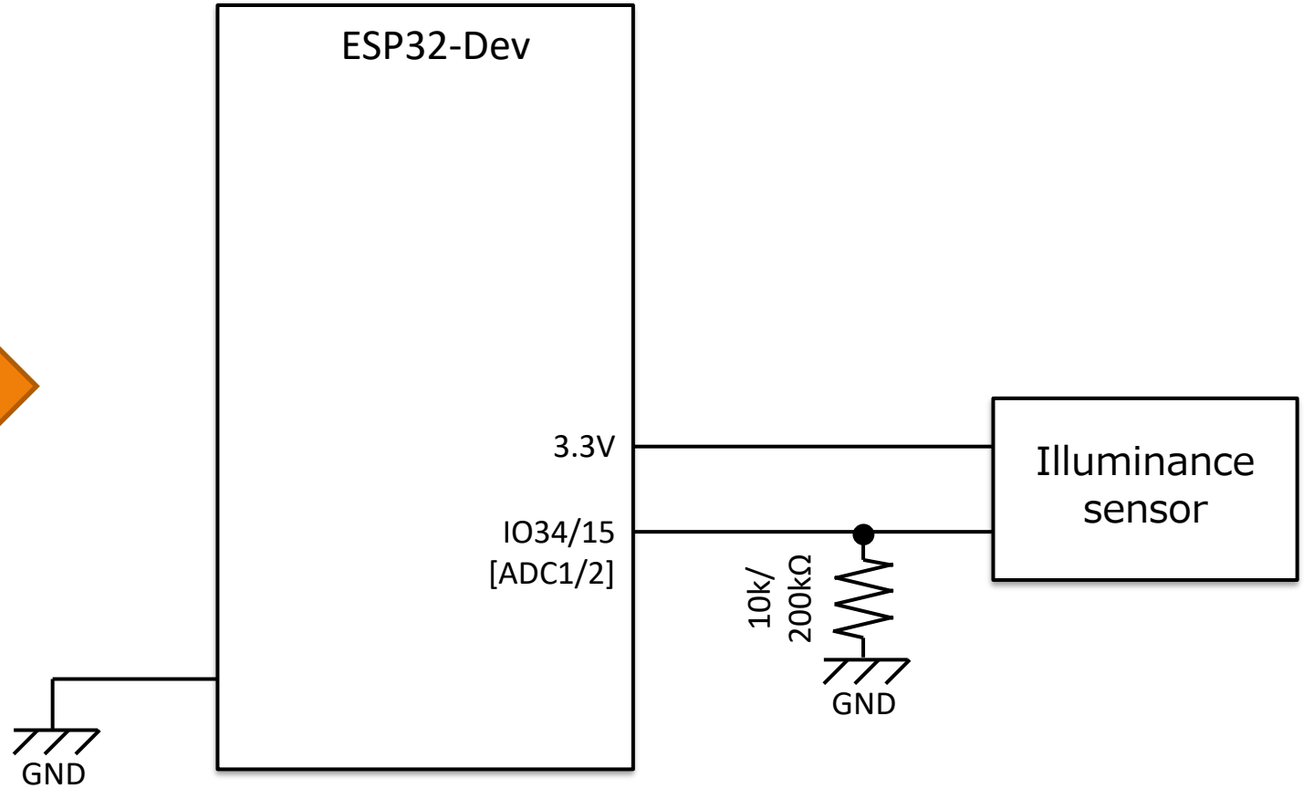
Please use an arbitrary value for the size of the resistance
depending on the brightness you want to measure.
This time, I used these three types to understand three different places from the graph.

9-1. Review circuit and resistance value

As the resistance value increases, the voltage increases even with the same current,
so I checked if the ESP32 can handle it.
Change the input voltage from 5V to 3.3V because it exceeds the allowable input voltage of 3.9V.
(Relationship graph of current lux is not available due to 5V input)

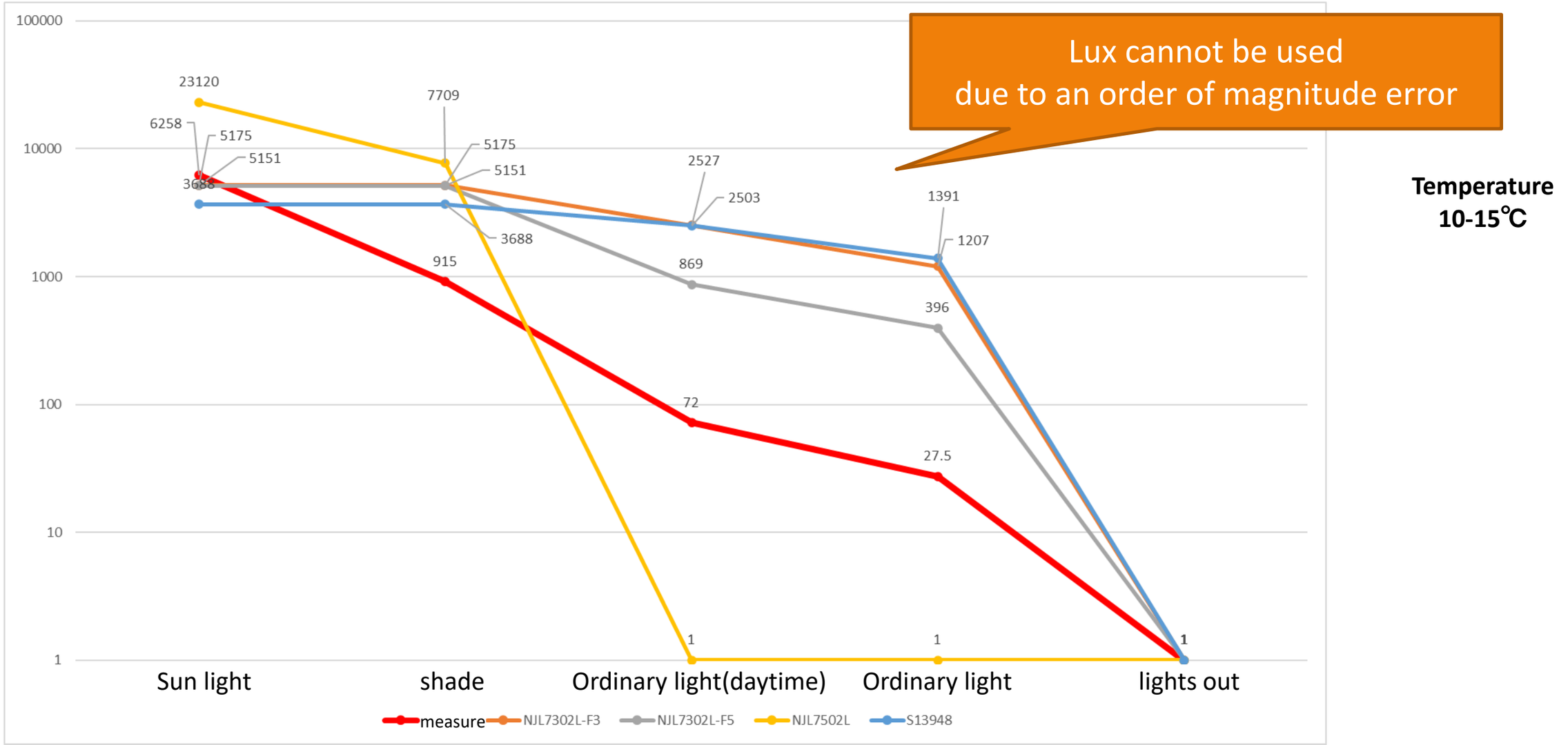


Because it exceeds 3.9V



reference. Measurement result 2 (5V, 10kΩ)

Just to make sure, I investigated whether lux measurement is possible.
(Originally, it cannot be used because it exceeds 3.9V)
Lux measurement is not possible due to an error of an order of magnitude. (Brightness can be reflected)



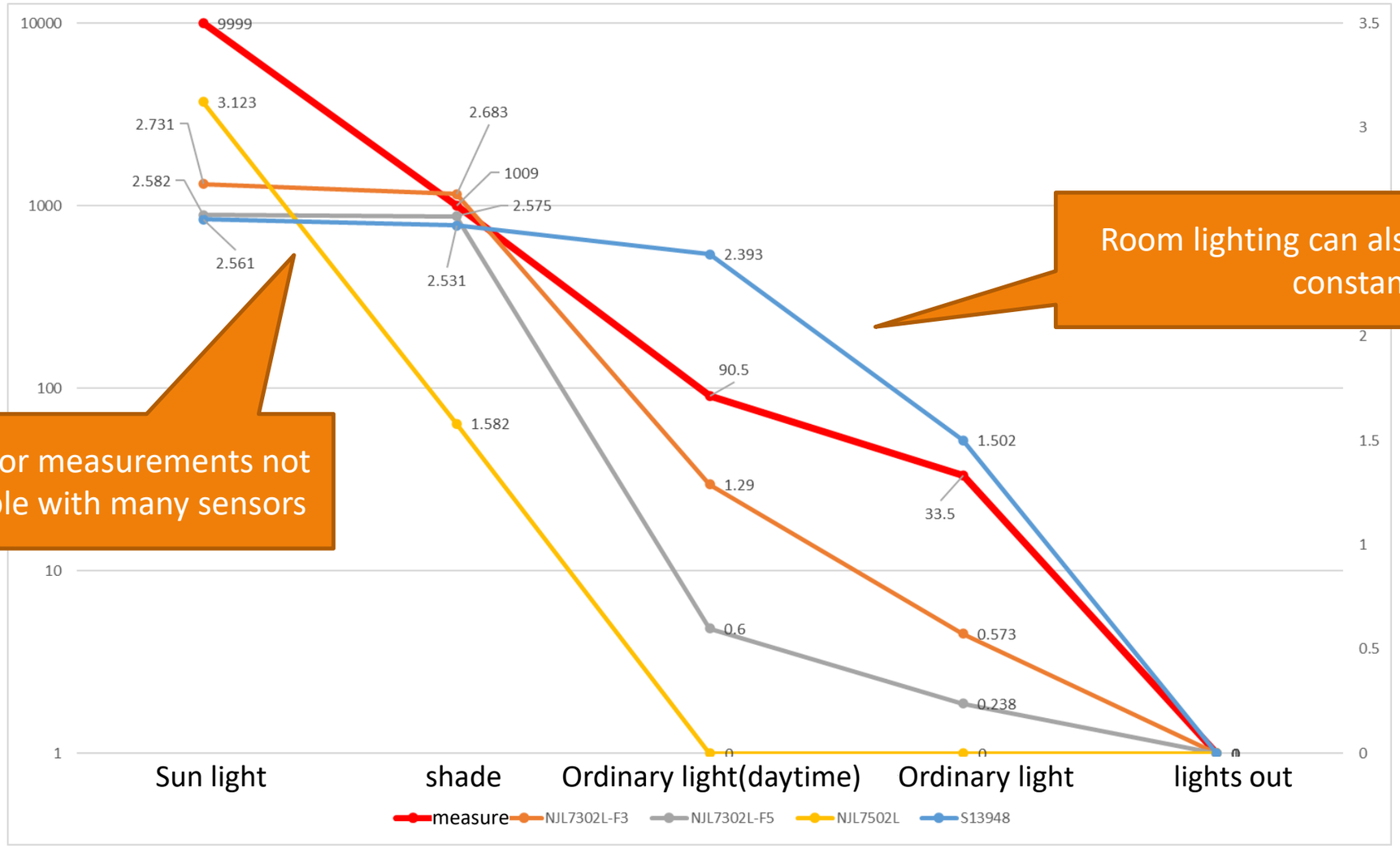
10-1. Measurement result 3 (3.3V, 10KΩ)

Using an input voltage of 3.3V and a resistance of 10KΩ,
it is possible to determine ON/OFF of the lighting in the room (other than NJL7502L)
However, it is desirable to use it when installing in a bright place because the value is low even in a relatively bright place.

Lux (measuring instrument)

Voltage (sensor)

Temperature 10-15℃

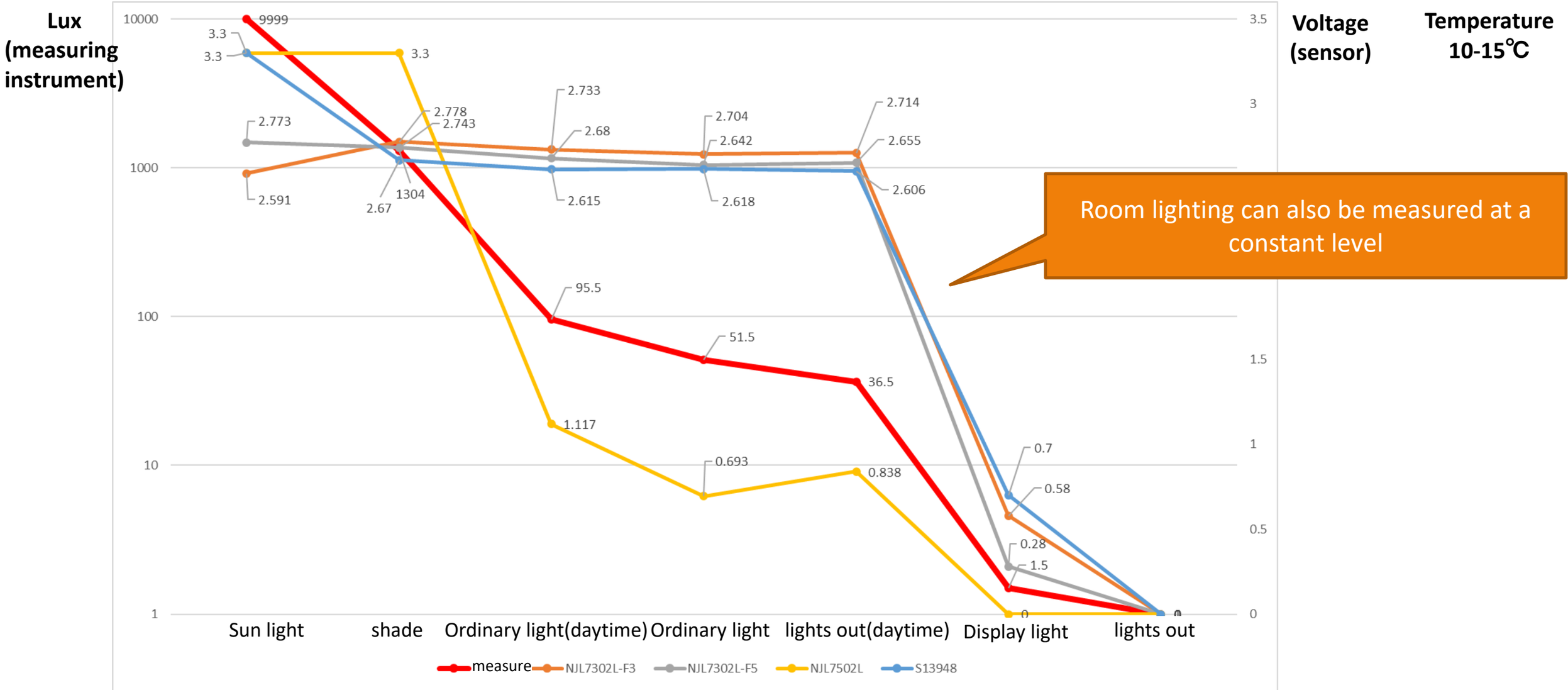


Outdoor measurements not possible with many sensors

Room lighting can also be measured at a constant level

10-2. Measurement result 4 (3.3V, 200KΩ)

Using an input voltage of 3.3V and a resistance of 10KΩ, it is possible to determine whether the lighting in the room is ON/OFF.
Can be used when you want to determine whether the lighting is on or off in a dark place, such as when installed in the corner of a room.



11. summary

- For the sensor investigated this time, "lux measurement is not available" in the configuration using ESP32
- All sensors "can be used to reflect brightness". There is no big difference in terms of performance.
- For personal use, "NJL7302L-F3" looks good considering price and ease of use.
  However, it doesn't matter which sensor you choose.
- It is better to use different input voltages and resistance values depending on the application.
  (However, it is desirable to use the Grove sensor indoors because the resistance cannot be changed)

  -Sunlight, shade judgment etc. ⇒ Input voltage 5V, resistance 330Ω
  -Indoor lighting ON/OFF etc. (bright place) ⇒ Input voltage 3.3V, resistance 10KΩ
  -Indoor lighting ON/OFF etc. (dark place) ⇒ Input voltage 3.3V, resistance 200KΩ