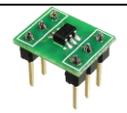
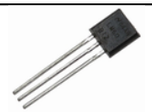
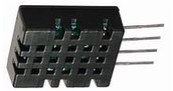
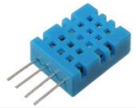
Temperature Sensor Investigation (Electronic work) [What is the first place?]

- Practical data when used with ESP32
- Investigation of 11 temperature sensors from 40 to 480 yen

Table of Contents

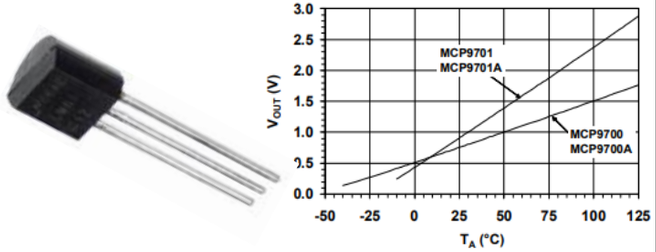
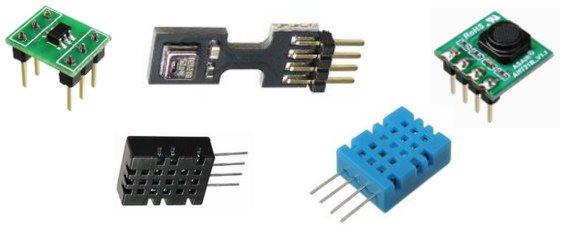
1. List of temperature sensors to investigate

NO	Product	Model number	Picture	URL	Price(Yen)	I/O vol	Temperatu	Accuracy	Accuracy	Note
1	Temperature sensor IC ＭＣＰ９７００－Ｅ／ＴＯ	MCP9700-E/TO		https://akizukidenshi.com/catalog/g/gI-09692/	40	2.3~5.5V -	-40~ +125°C	±4°C (Max)	-	10.0mV/° C
2	Temperature sensor IC ＭＣＰ９７００Ａ－Ｅ／ＴＯ	MCP9700A-E/TO		https://akizukidenshi.com/catalog/g/gI-14300/	100	2.3~5.5V -	-40~ +125°C	±2°C /0~70°C Oth±4°C	-	10.0mV/° C
3	Temperature sensor IC ＴＭＰ３６ＧＴ９Ｚ	TMP36GT9Z		https://akizukidenshi.com/catalog/g/gI-14188/	200	2.3~5.7V -	-40~ +125°C	~±3°C /25°C	-	10.0mV/° C
4	Ｓ－５８５１Ａ digital temperature sensor module	S-5851AAA-M6T1U		https://akizukidenshi.com/catalog/g/gM-11575/	110	2.7~5.5V -	-40~ +125°C	±2°C/- 25~85°C Oth±3°C	-	You can purchase the sensor only [¥100]
5	Temperature sensor IC ＬＭ３３５Ｚ	LM335Z		https://akizukidenshi.com/catalog/g/gI-11158/	100	5~40V -	-40~ +100°C	±4°C (Max)	-	10.0mV/K ・Operating current: 400μA~5mA
6	Temperature sensor IC ＬＭ６１ＣＩＺ	LM61CIZ		https://akizukidenshi.com/catalog/g/gI-11160/	120	2.7~10V -	-30~ +100°C	±3°C/- 25~85°C Oth±4°C	-	10.0mV/° C Vo=(+10mV/°C×T°C)+600mV
7	Temperature sensor IC ＬＭ６０ＢＩＺ	LM60BIZ		https://akizukidenshi.com/catalog/g/gI-02490/	180	2.7~10V -	-25~ +125°C	±3°C/- 25~125°C Oth±4°C	-	6.25 mV/° C
8	Temperature and humidity sensor ＡＨＴ２５	AHT25		https://akizukidenshi.com/catalog/g/gM-16731/	350	2.2~5.5V -	-40~ +80°C	±0.3°C	±2%RH	
9	Temperature and humidity sensor ＤＨＴ２０	DHT20		https://akizukidenshi.com/catalog/g/gM-16732/	380	2.2~5.5V -	-40~ +80°C	±0.5°C	±3%RH	
10	Temperature and humidity sensor ＡＨＴ２１Ｂ	AHT21B		https://akizukidenshi.com/catalog/g/gK-17394/	400	2.2~5.5V -	-40~ +80°C	±0.5°C	±5%RH	
11	Temperature and humidity sensor ＤＨＴ１１	DHT11		https://akizukidenshi.com/catalog/g/gM-07003/	480	3.3~5.5V -	0~ +50°C	±2°C	±5%RH	
Total					**2,460**	Separate shipping fee required				

Selection criteria (IT Taro survey)
- 3.3V/5V compatible
- Room temperature(0 to 40 ℃)
- Choose from the lowest price

1. Temperature sensor to investigate (in specifications)

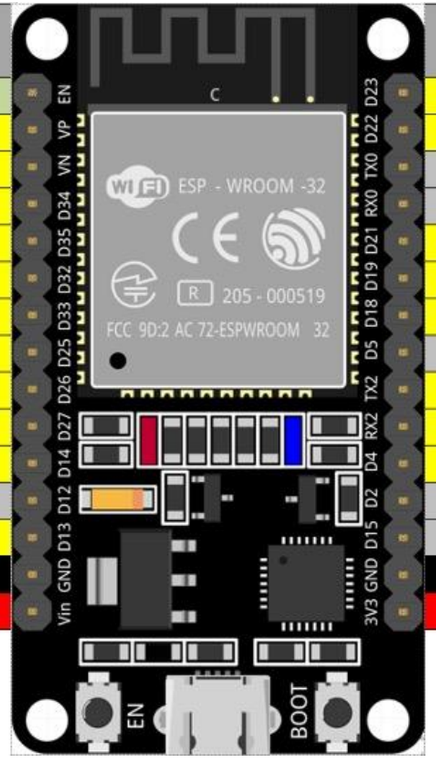
Voltage output type for price, Data output type for accuracy. In addition, voltage output can be difficult to examine circuits and calculation formulas, and data output tends to complicate I2C programming without a library.

Temperature sensor	Content	ESP32 Input terminal (port)	Circuit/wiring	Programming	Note
<Type> Voltage output [Temperature sensor IC]  [MCP9700/9700A,TMP36, LM335Z,LM61,LM60]	Output temperature difference as voltage cheap price Since voltage measurement [mV] is required, microcomputers tend to have poor accuracy.	ADC (voltage measurement) (Analog to Digital Converter) ESP32 ADC Accuracy ADC2 is not compatible with Wi-Fi ESP32 only has 2 ADCs	fixed port Wi-Fi consideration required low accuracy Resistance required [LM335Z]	Voltage to temperature formula	nothing special
<Type> Data output  [S-5851A,AHT25,DHT20, AHT21B,DHT11]	Output temperature and humidity data inside the sensor More expensive than voltage output Microcomputer only acquires data, so accuracy is good	I2C [S-5851A,AHT25, DHT20,AHT21B] Fixed I2C port	fixed port Need to consider address collision	I2C is difficult Library [AHT21B]	nothing special
		GPIO（Serial communication） [DHT11]	high degree of freedom	Library [DHT11]	Less accurate than I2C products

2. ESP32 port

● ESP32 port configuration

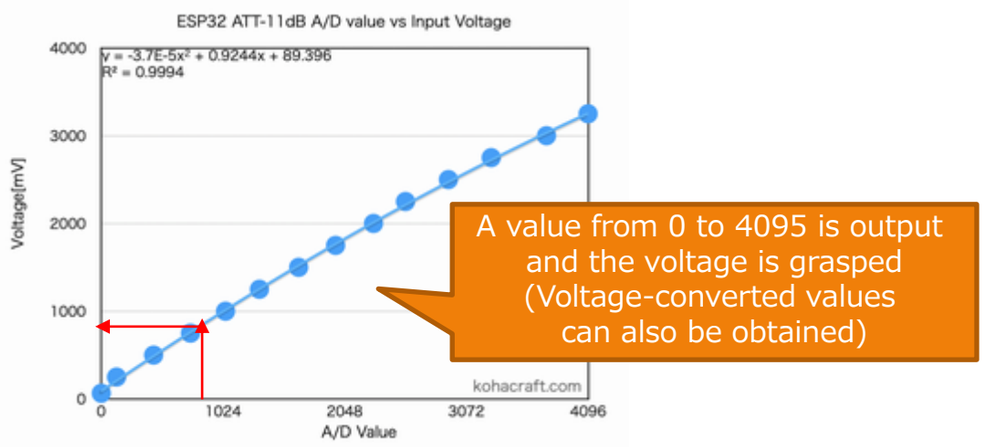
Touch	SPI/ DAC	Analog (ADC)		IO
				EN
		1-0	A0	GPI 36(VP)
		1-3	A3	GPI 39(VN)
		1-6	A6	GPI 34
		1-7	A7	GPI 35
T9		1-4	A4	GPIO32
T8		1-5	A5	GPIO33
	DAC_1	2-8	A18	GPIO25
	DAC_2	2-9	A19	GPIO26
T7		2-7	A17	GPIO27
T6	HSPICLK	2-6	A16	GPIO14
T5	HSPIQ	2-5	A15	GPIO12
T4	HSPID	2-4	A14	GPIO13
				GND
				5V



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

● I2C terminal

This is a method advocated by Philips, and is one of the synchronous serial communication methods. Along with SPI, it is often used for data communication between microcomputers and sensors.

- The I2C interface is as follows.
  SCL: GPIO22
  SDA: GPIO21
- The address of the device to be connected is fixed, and multiple connections are possible.

3－1/2. MCP9700/9700A

[Reference URL]
https://akizukidenshi.com/download/mcp9700.pdf
http://ww1.microchip.com/downloads/en/devicedoc/20001942g.pdf

MCP9700

MCP9700A

- Wide operating temperature: -40~+125℃
- Accuracy: ~±2℃/0~70℃ ~±4℃/-40~125℃
- **Output voltage: 500mV/0℃**
- **Optimal for ADC: 10.0mV/℃ (typ.)**
- Wide operating voltage range: 2.3 to 5.5V
- Low current consumption: 6μA (typ.)

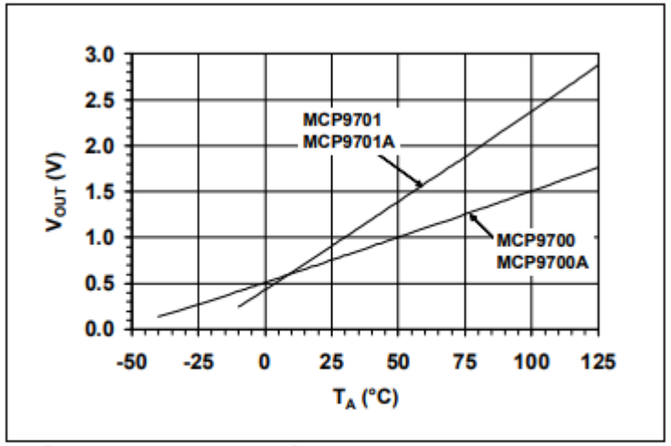
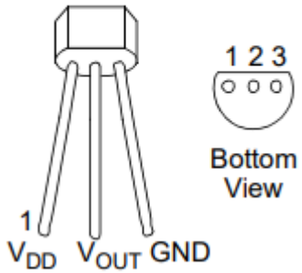


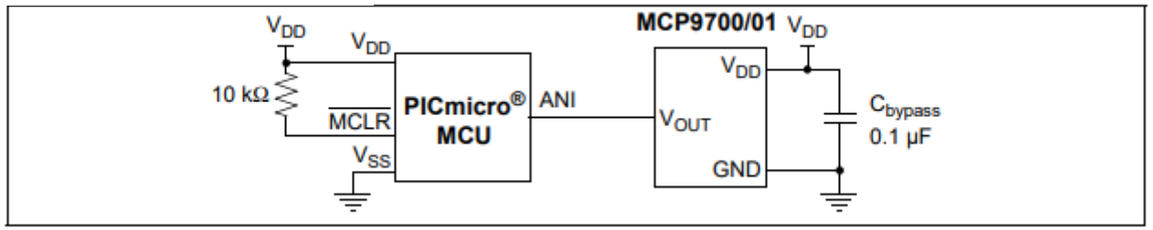
FIGURE 2-16: *Output Voltage vs. Ambient Temperature.*

T = (V[mV] – 500) / 10

3-Pin TO-92
MCP9700/9700A
MCP9701/9701A



Typical Application Circuit



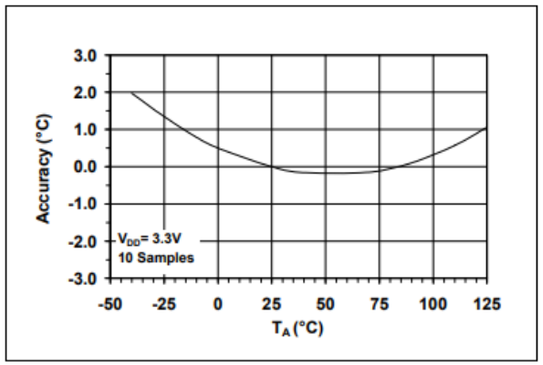


FIGURE 4-2: *Relative Accuracy to +25°C vs. Temperature.*

3－1/2. MCP9700/9700A　Programming

● Global definition

```
10 #define ADC1_PIN 34
11 #define ADC2_PIN 15
```

ADC port definition

●In the setup function

```
25   pinMode(ADC1_PIN, ANALOG);
26   pinMode(ADC2_PIN, ANALOG);
```

ADC port settings

●In the loop function

```
42   // ADC1[MCP9700]
43   uint16_t analog1_adc = analogRead(ADC1_PIN);
44   uint32_t analog1_mv = analogReadMilliVolts(ADC1_PIN);
45   double temprature1 = double(analog1_mv - 500) / 10.0;
46   Serial.printf("[%ld] MCP9700 ADC=%d, mV=%d[mV], temprature=%2.2f[°]\n", loopCount, analog1_adc, analog1_mv, temprature1);
47   // ADC2[MCP9700A]
48   uint16_t analog2_adc = analogRead(ADC2_PIN);
49   uint32_t analog2_mv = analogReadMilliVolts(ADC2_PIN);
50   double temprature2 = double(analog2_mv - 500) / 10.0;
51   Serial.printf("[%ld] MCP9700A, ADC=%d, mV=%d[mV], temprature=%2.2f[°]\n", loopCount, analog2_adc, analog2_mv, temprature2);
```

T = (V[mV] – 500) / 10

ADC measurement (mV)

Converts measured voltage to temperature

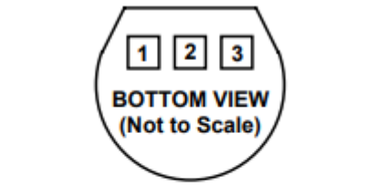
Display calculation result on serial monitor

Voltage output type sensors can be similarly programmed

3－3. TMP36GT9Z

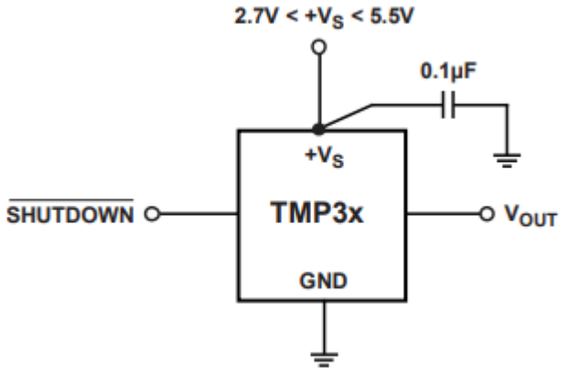
[Reference URL]
https://akizukidenshi.com/download/ds/analog/tmp35_36_37_jp.pdf

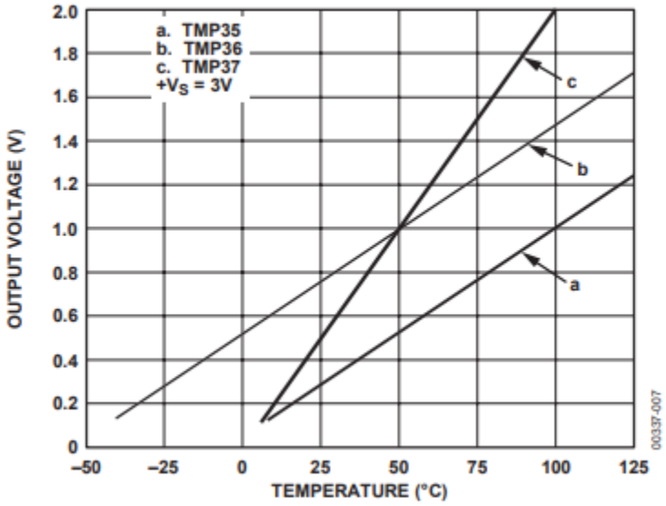
- Power supply voltage: 2.7~5.5V
- Output type: Analog output
- Measurement temperature range: -40 to 125℃
- **Output voltage: 750mV/25℃**
- **Scale factor: 10mV/℃**
- Accuracy: ~±3℃/25℃
- Linearity: ±0.5℃
- Current consumption: ~50μA



PIN 1, $+V_S$; PIN 2, V_{OUT}; PIN 3, GND

図 4.T-3 (TO-92)

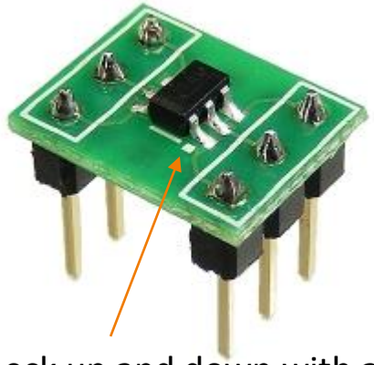




T = (V[mV] – 500) / 10

3－4. S-5851AAA-M6T1U

[Reference URL]
https://www.ablic.com/jp/doc/datasheet/temperature_sensor/S5851A_J.pdf
https://playground.arduino.cc/Main/I2cScanner/
https://www.denshi.club/cookbook/arduino/spresense/spresensel-18-wire-s-5851a.html



Check up and down with a point

Power supply voltage 2.7 to 5.5V
Consumption current 45uA. 1uA in standby
Measurement temperature range -40 to 125°C. ±0.5°C (-25 to +85°C)
accuracy with **0.0625°C** resolution (12 bits)
Interface I2C (maximum 400kHz)
Data length 12 bits in 2's complement format
Slave address: Set with AD0 and AD1 pins

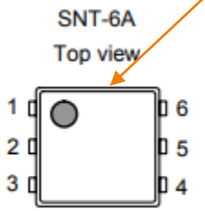


Figure 2

Table 2

Pin No.	Symbol	Description
1	AD1	Address input
2	VSS	GND
3	SCL	Input for serial clock
4	SDA	I/O for serial data
5	AD0	Address input
6	VDD	Power supply

Remark See Dimensions for details of the package drawings.

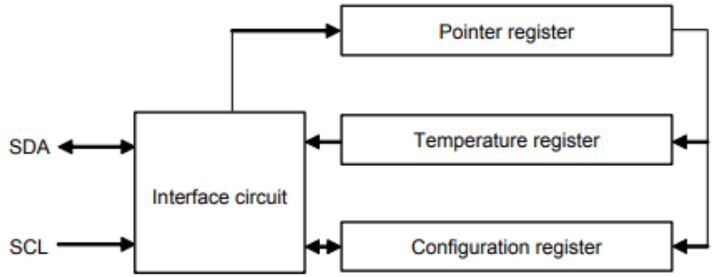


Figure 11 Configuration of Register

Table 11 Settings for Address Input Pin and Slave Address

Settings for address input pin		Slave address			
AD1 pin	AD0 pin	Device code	A2	A1	A0
0	0	1001	0	0	0
0	Open		0	0	1
0	1		0	1	0
1	0		1	0	0
1	Open		1	0	1
1	1		1	1	0
Open	0		0	1	1
Open	1		1	1	1

I2C Address
0x48

Data 4bit shift

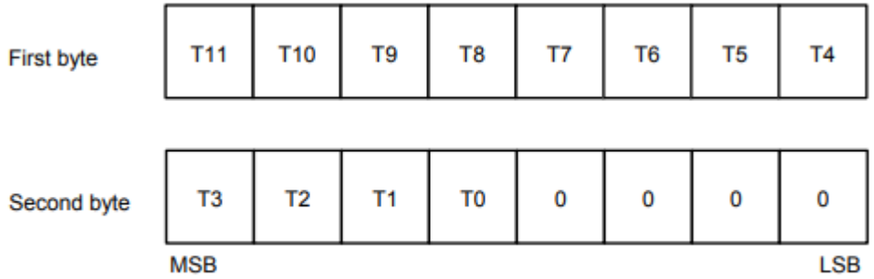


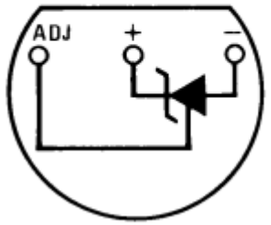
Figure 13 Configuration of Temperature Register

3－5. LM335Z

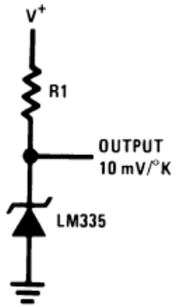
[Reference URL]
https://www.ti.com/product/ja-jp/LM335
https://www.denshi.club/cookbook/sensor/temp/3mcp9700.html

- **Output: 10mV/°K**
- Dynamic impedance: 1Ω or less
- Operating current: 400μA~5mA
- Measuring range: -40 to 100℃ (continuous)
- TO-92 package
- **Input voltage: 5 to 40V**

TO-92 (LP)
3 Pins
Bottom View



Basic Temperature Sensor Simplified Schematic



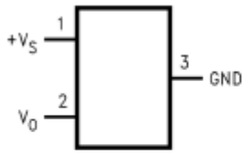
T = (V[mV] / 10) – 273.15

3－6. LM61CIZ

[Reference URL]
https://www.tij.co.jp/jp/lit/ds/symlink/lm61.pdf

- Measurement range: -30℃~100℃
- Temperature coefficient: +10mV/°C
- Operating voltage range: +2.7 to +10V
- Output impedance: 800Ω
- **Vo=(+10mV/℃×T℃)+600mV**

DBZ Package
3-Pin SOT-23
Top View



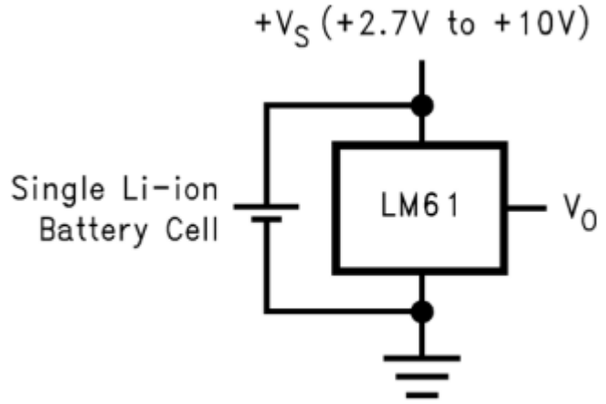
LP Package
3-Pin TO-92

BOTTOM VIEW

Pin Functions

PIN		TYPE	DESCRIPTION
NAME	NO.		
+VS	1	Power	Positive power supply pin.
VOUT	2	Output	Temperature sensor analog output.
GND	3	Ground	Device ground pin, connected to power supply negative terminal.

Typical Application



$V_O = (10mV/℃ \times T℃) + 600mV$

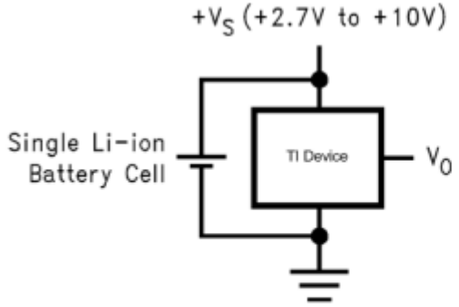
T = (V[mV] – 600) / 10

3－7. LM60BIZ

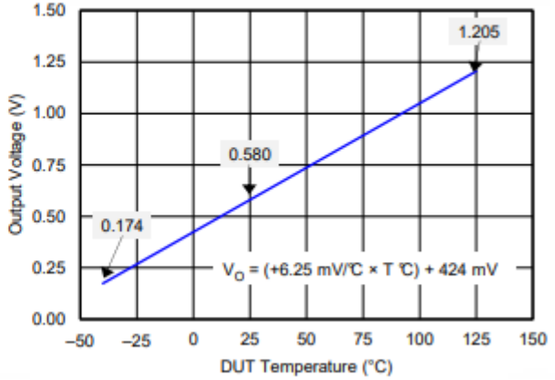
[Reference URL]
https://www.tij.co.jp/jp/lit/ds/symlink/lm60.pdf

- Output format: Analog
- Operating voltage: DC2.7V~10V
- Measurement range: -25 to +125°C **6.25mV per 1°C**
- Error: ±2°C (@25°C)

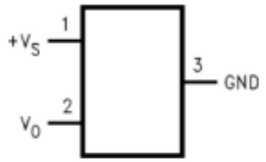
Typical Application



Temperature graph



DBZ Package
3-Pin SOT-23
Top View



LP Package
3-Pin TO-92
Bottom View

Pin Functions

PIN			TYPE	DESCRIPTION
NAME	SOT-23	TO92		
GND	3	3	GND	Device ground, connected to power supply negative terminal
V_{OUT}	2	2	O	Temperature sensor analog output
$+V_S$	1	1	POWER	Positive power supply pin

T = (V[mV] – 424) / 6.25

3－8. AHT25

[Reference URL]
https://akizukidenshi.com/download/ds/aosong/AHT25.pdf
https://qiita.com/ayakix/items/69cf14e57dec86f4415a

- Power supply voltage: 3.3V (2.2 to 5.5V)
- Current consumption: 980 μA (when measuring), 250 nA (not measuring)
- Measurement interval: Recommended every 2 seconds or more
- Humidity measurement range: 0 to 100% RH
- Humidity resolution: 0.024%
- Humidity accuracy: ±2%RH
- Temperature measurement range: -40 to 80℃
- Temperature accuracy: ±0.3℃
- Output format: **I2C** (100kHz/400kHz) **0x38** (7bit address)
- Output data: humidity 20bit, temperature 20bit

Pins	Name	Describe
1	VDD	Power supply(2.2v to 5.5v)
2	SDA	Serial Data Bidirectional port
3	GND	Ground
4	SCL	Serial clock Bidirectional port

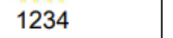


Table 5. ATH21B pin distribution (top view)

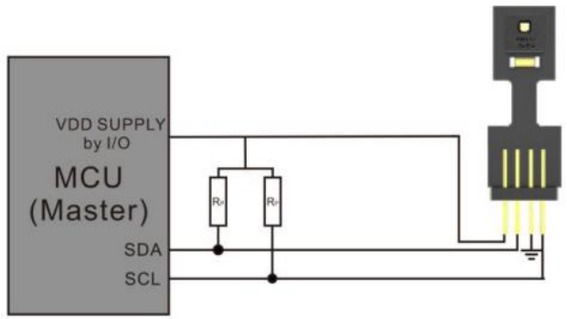
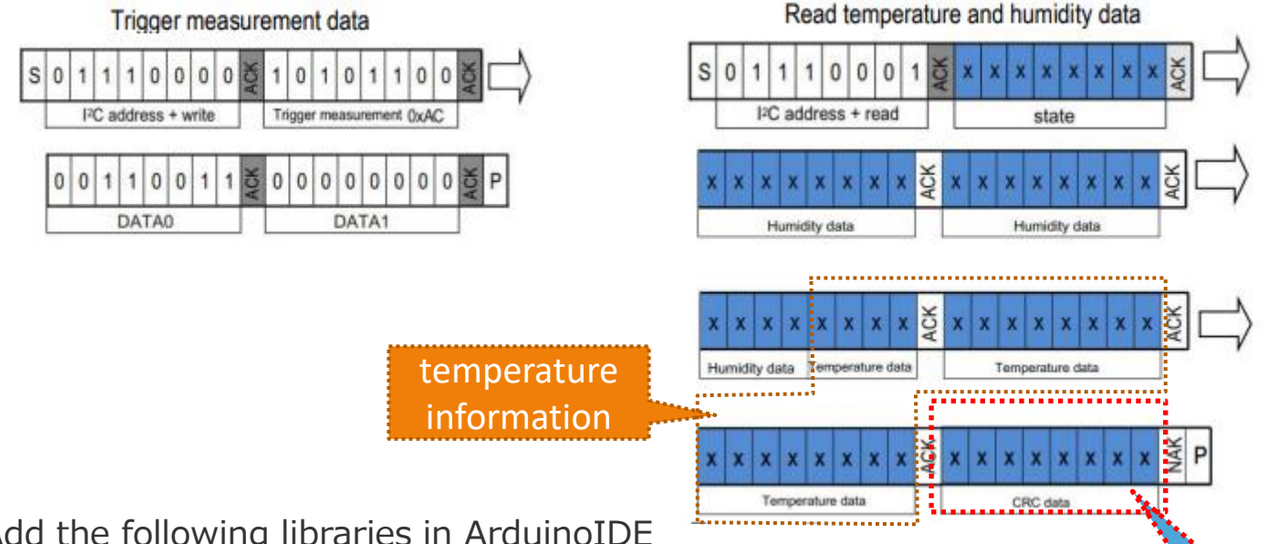
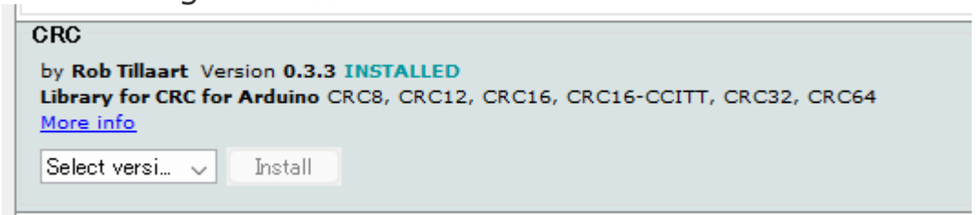


Figure 8. Typical application circuit



Add the following libraries in ArduinoIDE



3－9. AHT21B

[Reference URL]
https://akizukidenshi.com/download/ds/aosong/AHT21B.pdf

- Power supply voltage: 3.3V (2.2 to 5.5V)
- Current consumption (when measuring): 980μA
- **Interface: I2C**
- Resolution (humidity): 0.024%RH
- Accuracy (humidity): ±3% RH
- Operating range (humidity): 0 to 100% RH
- Resolution (temperature): 0.01℃
- Accuracy (Temperature): ±0.5℃
- Operating range (temperature): -40 to +80℃

5 Interface Definition

Pins	Name	Describe
1	VDD	Power supply(2.2v to 5.5v)
2	SDA	Serial Data Bidirectional port
3	GND	Ground
4	SCL	Serial clock Bidirectional port

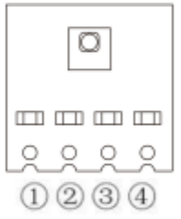


Table 5. ATH21B pin distribution (top view)

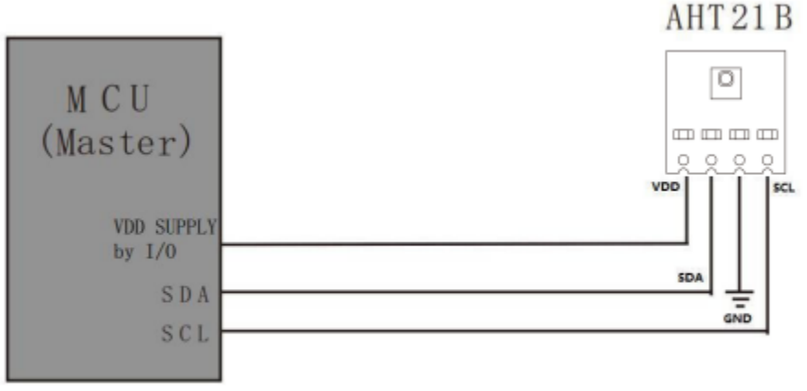


Figure 8. Typical application circuit

Add the following libraries in ArduinoIDE

Adafruit AHTX0

by **Adafruit** Version **2.0.3** INSTALLED
Arduino library for the AHT10 and AHT20 sensors in the Adafruit shop Arduino library for the AHT10 and AHT20 sensors in the Adafruit shop
More info

3－10. DHT20

[Reference URL]
https://akizukidenshi.com/download/ds/aosong/DHT20.pdf
https://hatakekara.com/dht20-arduino/

- Power supply voltage: 3.3V (2.2 to 5.5V)
- Current consumption: 980μA (250nA at standby)
- Measurement interval: recommended every 2 seconds
- Dimensions: 16.1mm (not including pin length) x 12.6mm x 5.8mm
- Pin pitch: 2.54mm
- Humidity measurement range: 0 to 100% RH
- Humidity resolution: 0.024%RH
- Humidity accuracy: ±3%RH
- Humidity repeatability: 0.1%RH
- Humidity response time: within 8 seconds
- Temperature measurement range: -40 to 80℃
- Temperature resolution: 0.01℃
- Temperature accuracy: ±0.5℃
- Temperature repeatability: ±0.1℃
- Temperature response time: 5 to 30 seconds
- **Output format: I2C (100kHz/400kHz), 0x38 (7bit address)**
- **Output data: humidity 20bit, temperature 20bit**

5 Interface Definition

Pins	Name	Describe
1	VDD	Power supply(2.2v to 5.5v)
2	SDA	Serial Data Bidirectional port
3	GND	Ground
4	SCL	Serial clock Bidirectional port

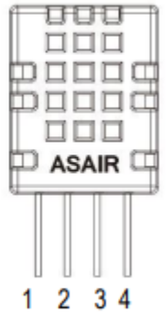


Table 5. ATH21B pin distribution (top view)

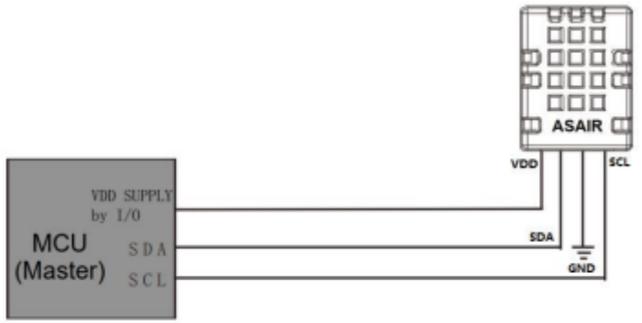
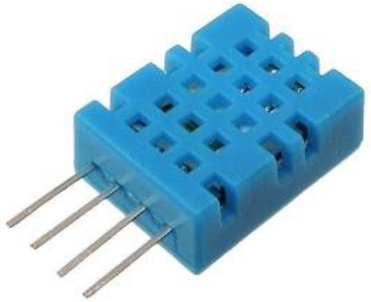


Figure 8. Typical application circuit

3－11. DHT11

[Reference URL]
https://akizukidenshi.com/download/ds/aosong/DHT11_20180119.pdf



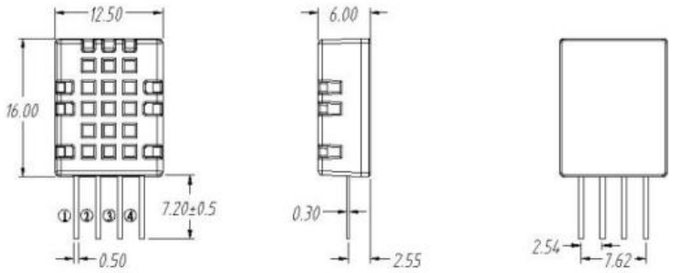


FIG. 1 product dimension diagram

Pin description

1. VDD power supply 3.3 ~ 5.5V DC
2. DATA serial DATA, single bus
3. NC empty feet
4. GND grounding, power supply negative

Typical circuits

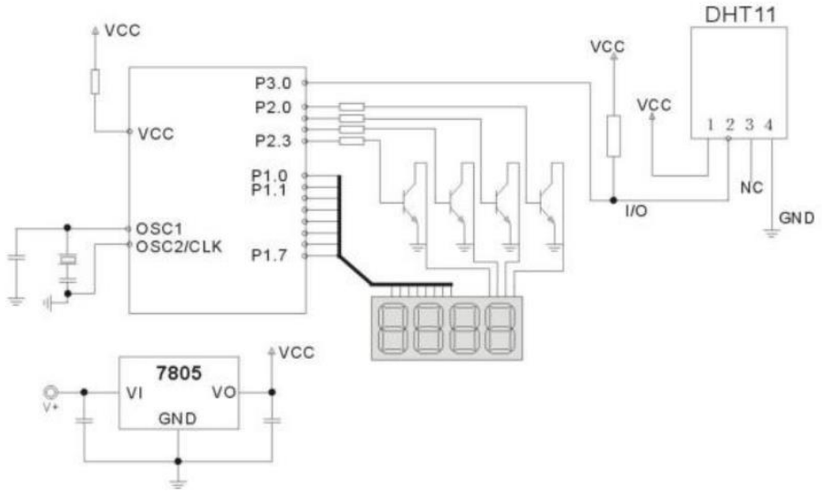


FIG. 1-2 DHT11

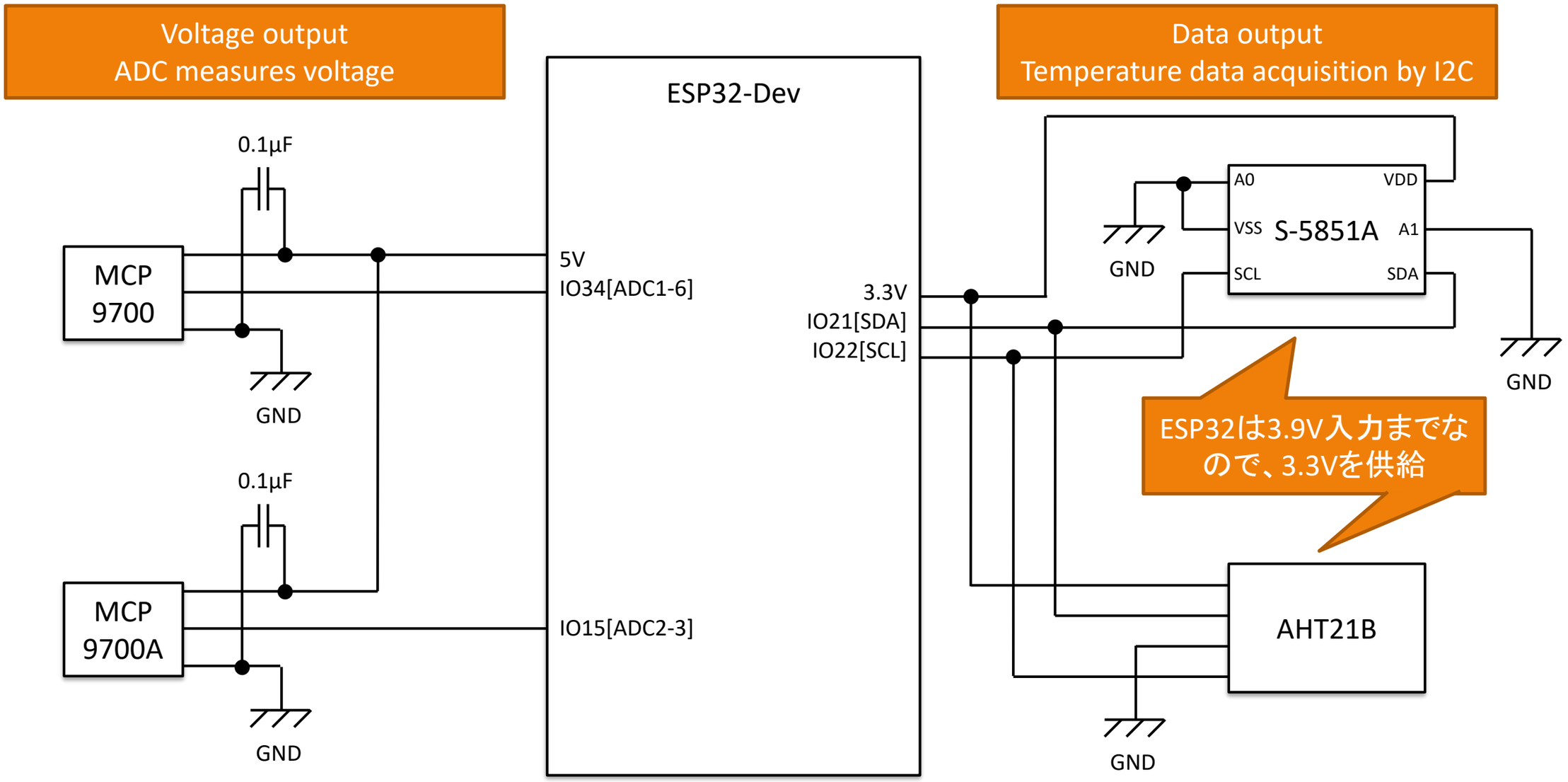
◆ Main specifications
・Power supply voltage: DC3.3V~5.5V
・Current consumption: 0.3mA (during measurement), 60μA (during standby)
・Sampling interval: 2 seconds or more
・Internal AD converter: 16bit each
・Size: 12 x 15.5 x 5.5mm (not including pins)
◆ Humidity sensor
・Sensor: Organic polymer
・Accuracy: ±5% RH (@25℃)
・Repeatability: ±1% RH
・Response: Within 6 seconds (1/e (63%), @25℃, wind speed 1m/s)
◆Temperature sensor
・Sensor: NTC thermistor
・Accuracy: ±2°C (@25°C)
・Repeatability: ±0.2℃
・Response: Within 10 seconds (1/e (63%))
◆**Serial communication part**
・Format: Single-wire bus (bi-directional), serial 40-bit configuration
・Output data: **Humidity 8bit** (Resolution: 1%RH), **Temperature 8bit** (Resolution: 1℃)
・Output: Open drain

Add the following libraries in ArduinoIDE

DHT sensor library
by **Adafruit** Version **1.4.4** **INSTALLED**
Arduino library for DHT11, DHT22, etc Temp & Humidity Sensors Arduino library for DHT11, DHT22, etc Temp & Humidity Sensors

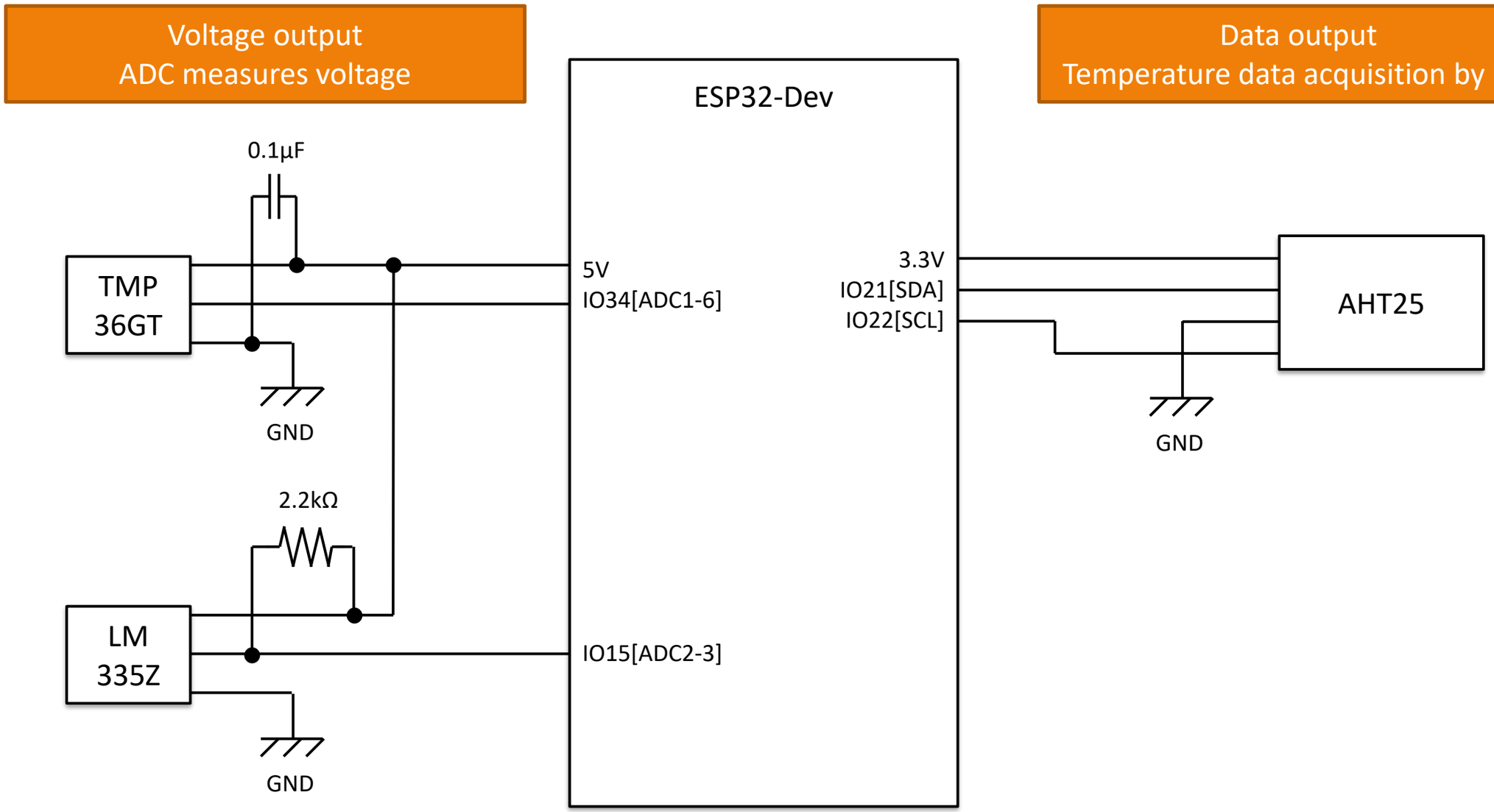
4-1. Circuit 1

Measure the voltage of MCP9700/9700A with ADC1,2 and calculate the temperature.
The S-5851A and AHT21B are connected to the I2C bus to acquire temperature data.



4-2. Circuit 2

Calculate the temperature by measuring the voltage of the TMP36GT with ADC1 and the LM335 with ADC2.
AHT25 uses I2C to acquire temperature data.

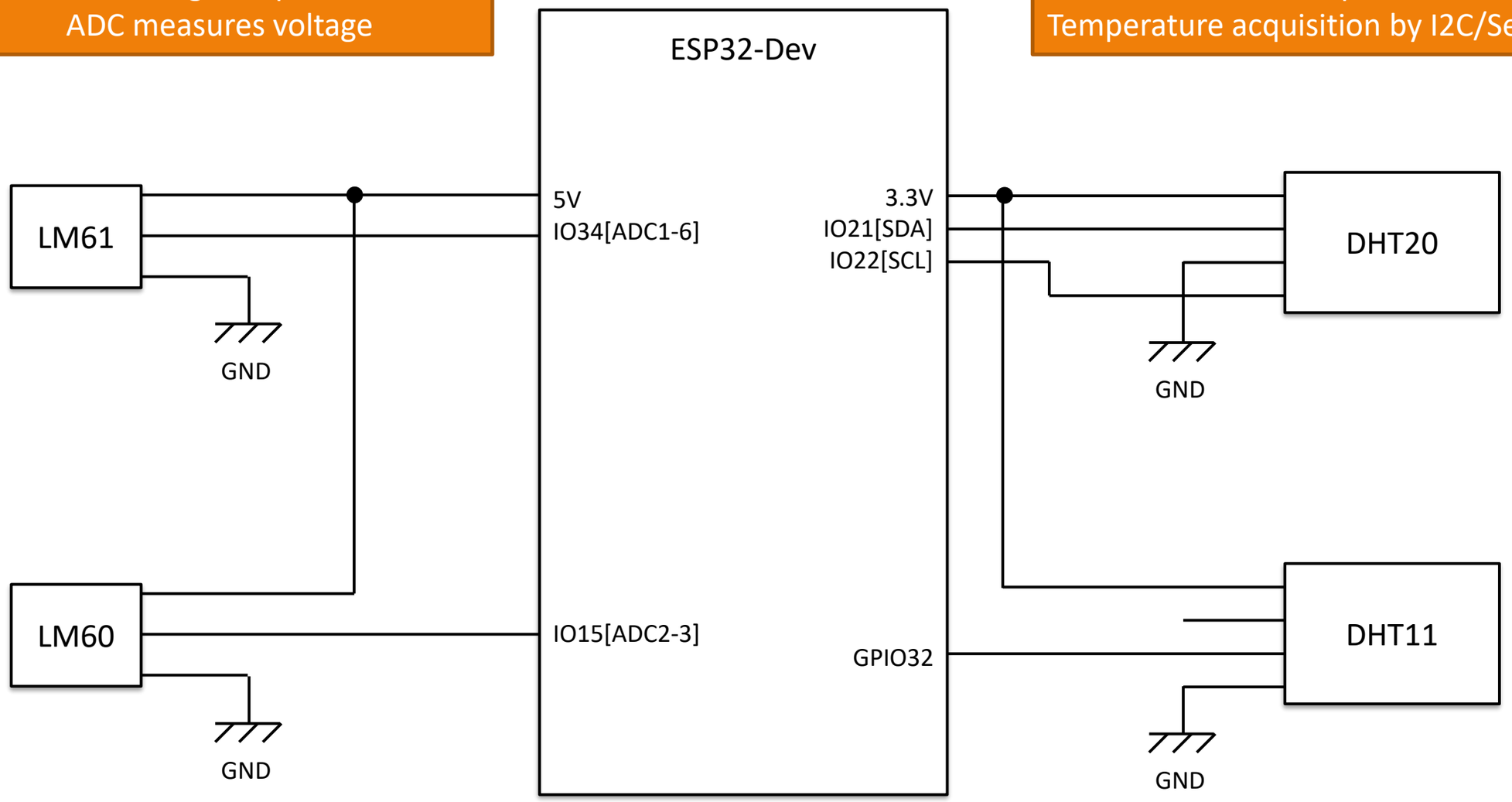


4-3. Circuit 3

Measure the voltage of LM60/LM61 with ADC1,2 and calculate the temperature.
DHT20 uses I2C and DHT11 uses GPIO32 to acquire temperature data.

Voltage output
ADC measures voltage

Data output
Temperature acquisition by I2C/Serial



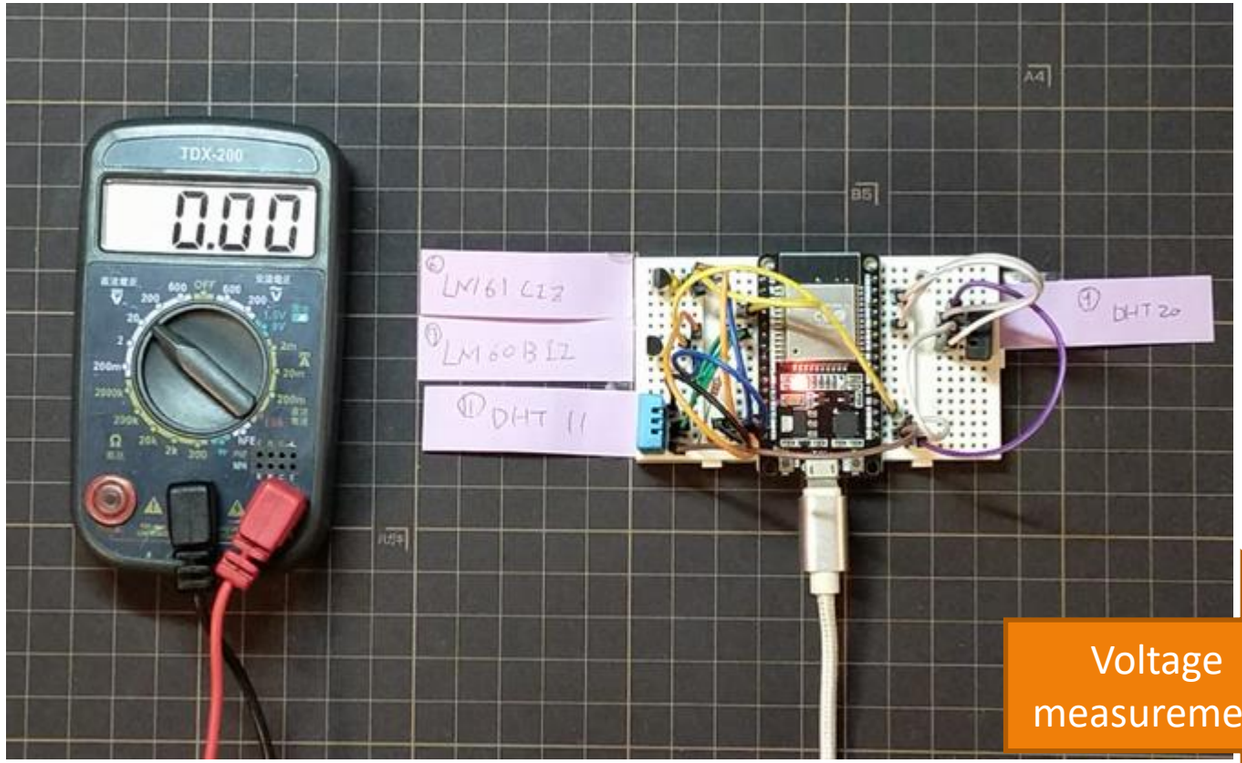
5. Measuring instrument (thermometer)

In order to measure the temperature as accurately as possible, four thermometers are prepared, and the average value is used by excluding the specific values that deviate greatly.

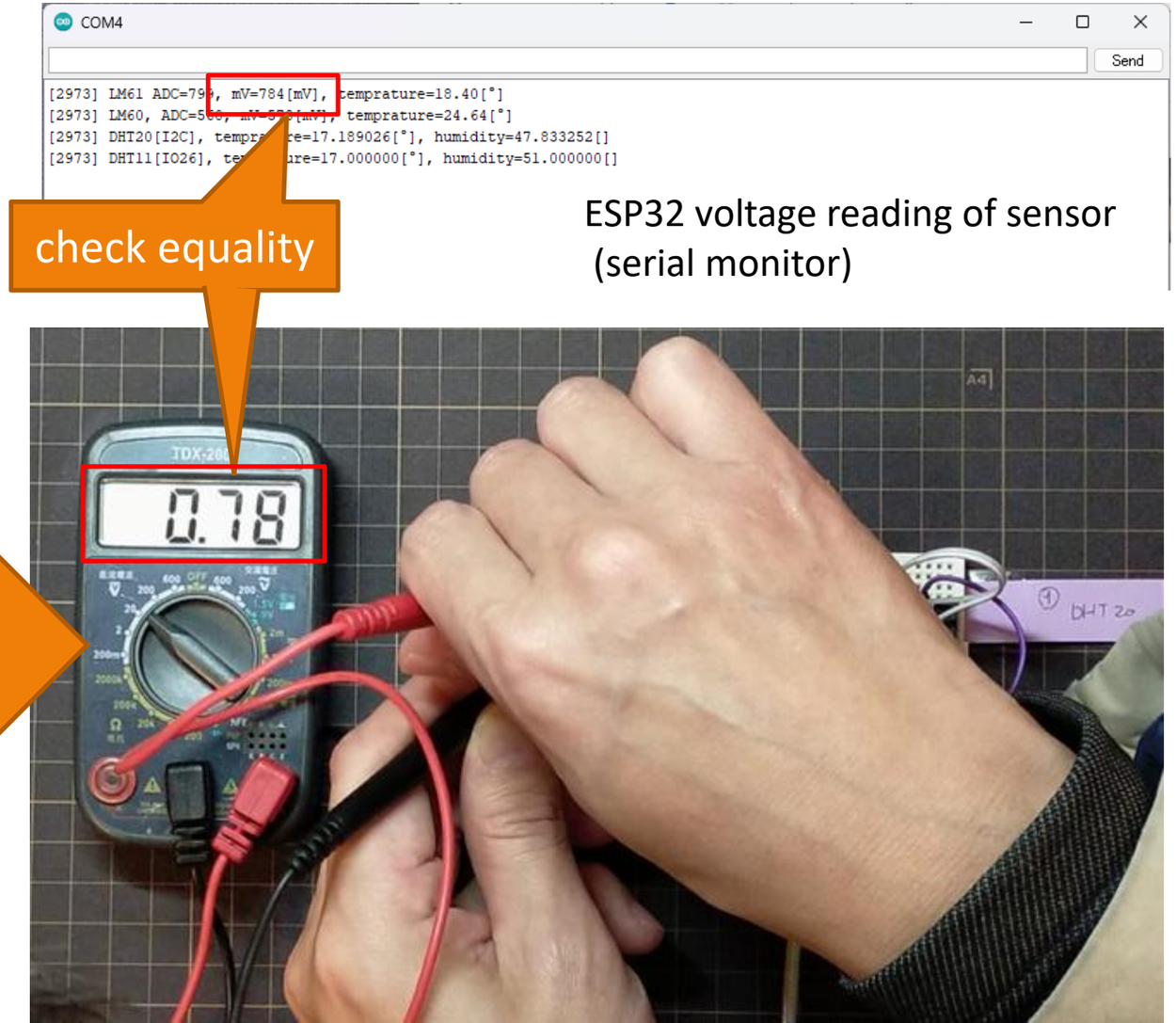
	Manufacturer	Model number		Measurement range (temperature humidity)	Accuracy (temperature humidity)
1	TANITA	Digital thermohygrometer TT-558		-5～50℃ 20～95%	0～40℃ ±1℃ （Other ±2℃） 35～75% ±5% （Other ±10%）
2					
3		Digital thermohygrometer TT-585		-5～50℃ 20～95%	0～40℃ ±2℃ （Other ±3℃） 35～75% ±5% （Other ±10%）
4	Shinwa measurement	72669 Thermo-hygrometer U-3(Round 6.5cm)		-24～50℃ 10～90%	-20～40℃ ±2℃ （Other ±4℃） 35～75% ±5% （Other ±10%）

6. Measurement result

Confirm that the voltage output of the sensor is equivalent to the ADC measurement result of ESP32 and the tester measurement.

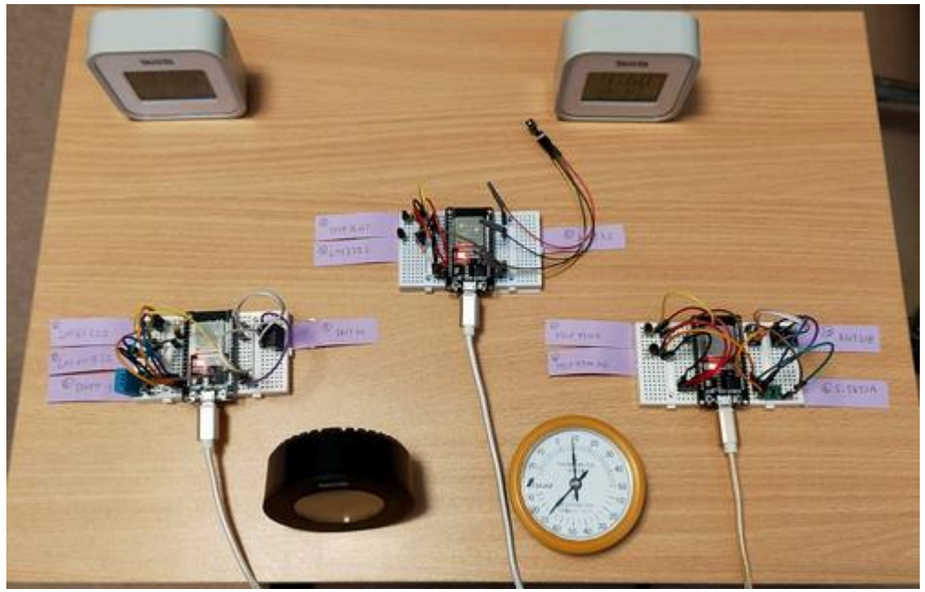


Voltage measurement

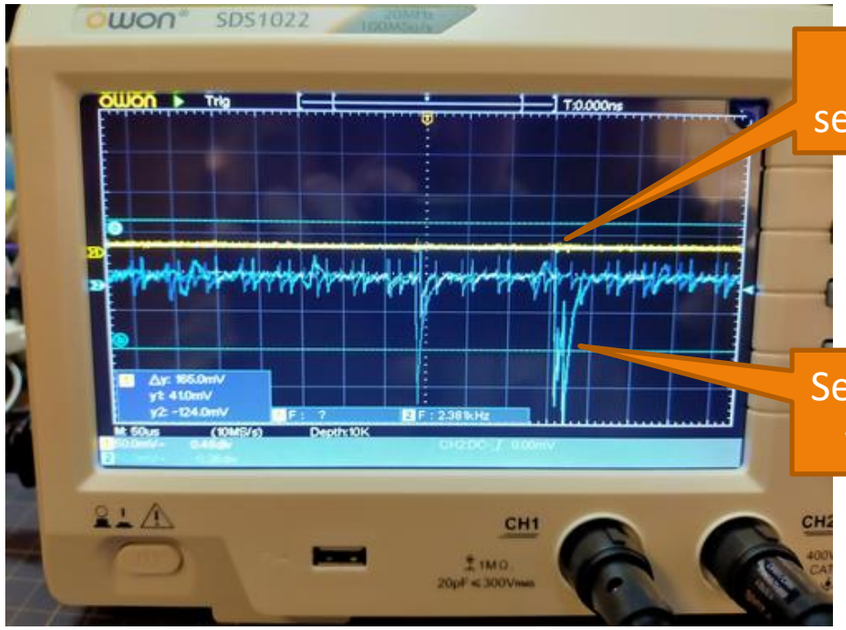


6. Measurement result

Since there is some variation in the ADC measurement results, the specific values that deviate greatly are excluded, and the average of the two measurements is taken.



Measure the temperature by installing four thermometers in a circle

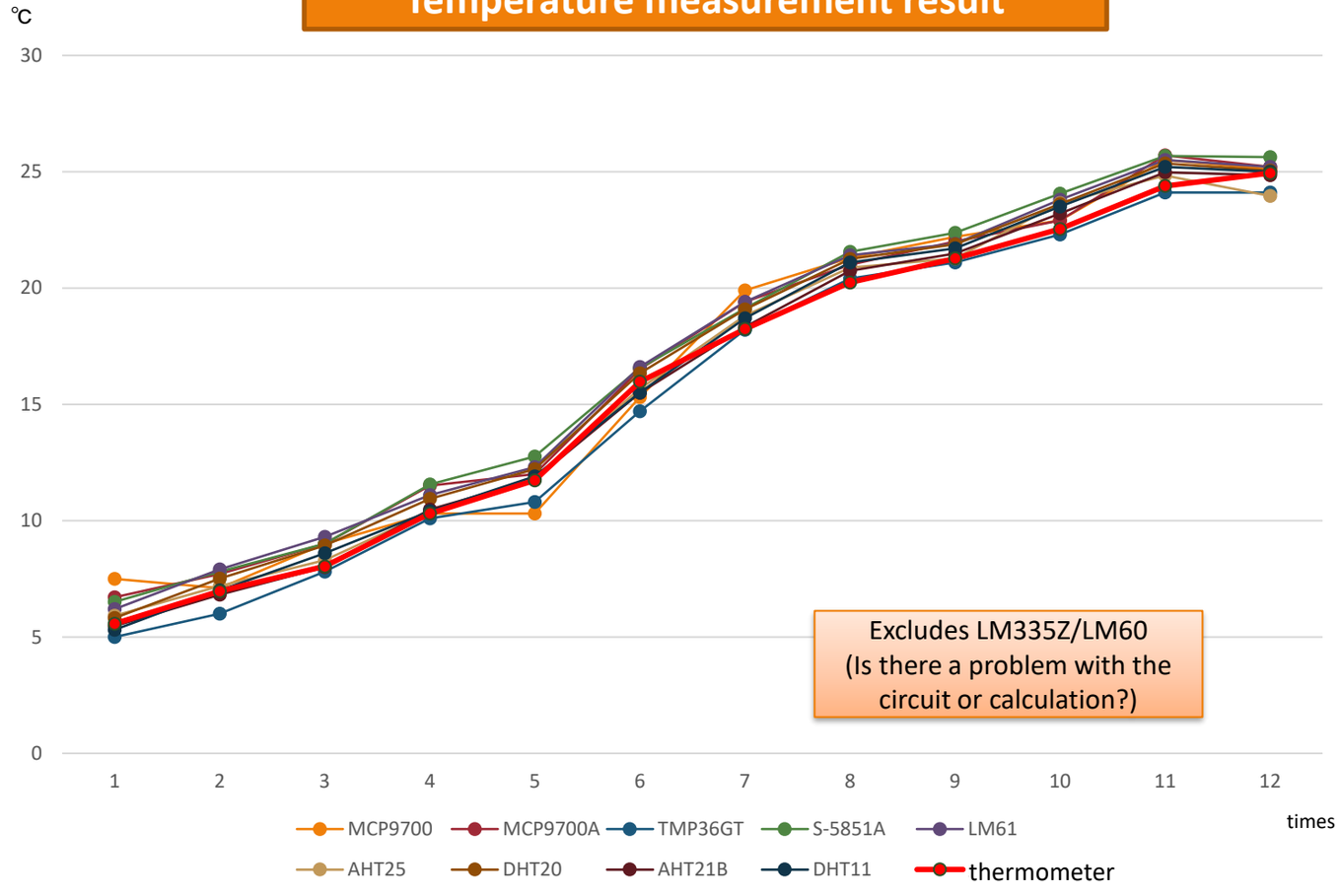


Some noise is seen in the voltage output of the temperature sensor IC
(Some sensors have almost no noise)

6. Measurement result

- The temperature measurement was within the tolerance of the specification. (Excluding LM335Z/LM60)
- The data output sensor (I2C/serial) tends to have a smaller error than the voltage output sensor
- Least error 1st place: AHT21B 2nd place: AHT25 3rd place: DHT11

Temperature measurement result



Error from thermometer