# Application Circuit of Low Noise Op-Amp TC75S67TU for Current Sensor

# Reference Guide

## RD161-RGUIDE-01

## Overview

This reference guide describes the specifications, board patterns, usage, and characteristics of the current sensor (hereinafter referred to as the "sensor") using the low-noise operational amplifier TC75S67TU. A microcontroller can be used to control operations and display results. Please refer to this section when designing a current sensor using a TC75S67TU.

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

# Table of Contents

# 1. Introduction

The current sensor described in this reference guide uses a simple-structured shunt resistor as the current sensing method. In addition to being able to measure currents up to 2 A, we also designed a GND sense and a ringing detection for current. It can be widely used for a variety of applications, current sensing for battery-powered devices such as notebook PCs and electronic cigarettes, and overcurrent protection for home appliances. Arduino is used for the microcontroller to control operations and to display the results on the computer. The power supply also uses a 5 V DC voltage supplied by Arduino, so it can be used as a current sensor if there is a Arduino and a personal computer in addition to this sensor.

To download of the various offer information on this sensor reference design → Click Here

The components other than the op-amp are also mounted on a compact board size of 20 mm x 20 mm using surface mount, making it easy to use for a variety of applications.

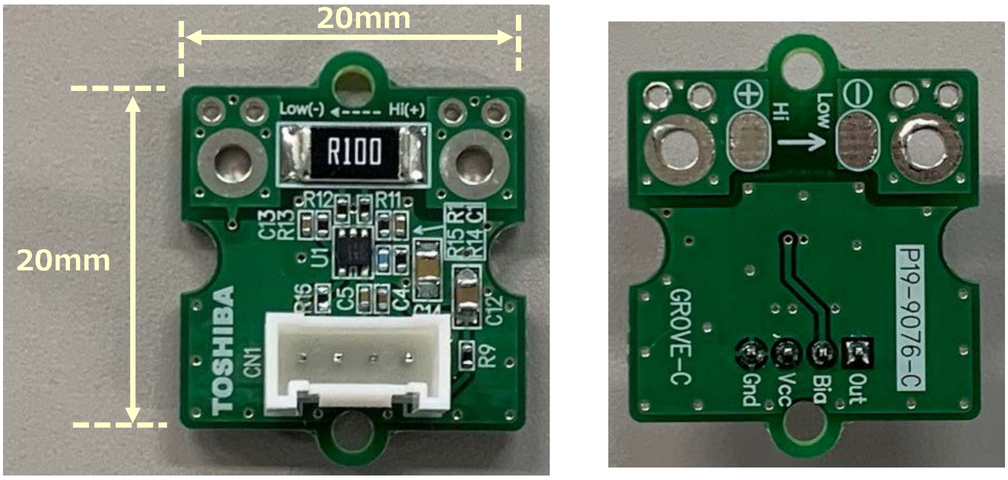
# 2. Specifications and Appearance

## 2.1. Specification

**Table 2.1 Current Sensor Circuit Specifications**

| Item | Specification |
|---|---|
| I/F | Arduino connectivity |
| Control method | Control from Arduino and Shield connected PCs |
| Power supply voltage | Arduino and Shield board feed 5 V |
| Measured current | Maximum 2 A |
| Shunt resistor | RL73H3AR10FTE of TE connectivity<br>100 mΩ, ±1 % accuracy, 1 W@70 °C |
| On-board operational amplifier | Toshiba Device & Storage TC75S67TU |

## 2.2. Appearance



**Top (parts mount side)**

**Bottom**

Fig. 2.1 Current Sensor Appearance

# 3. Circuit and Board Pattern

## 3.1. Circuit Diagram

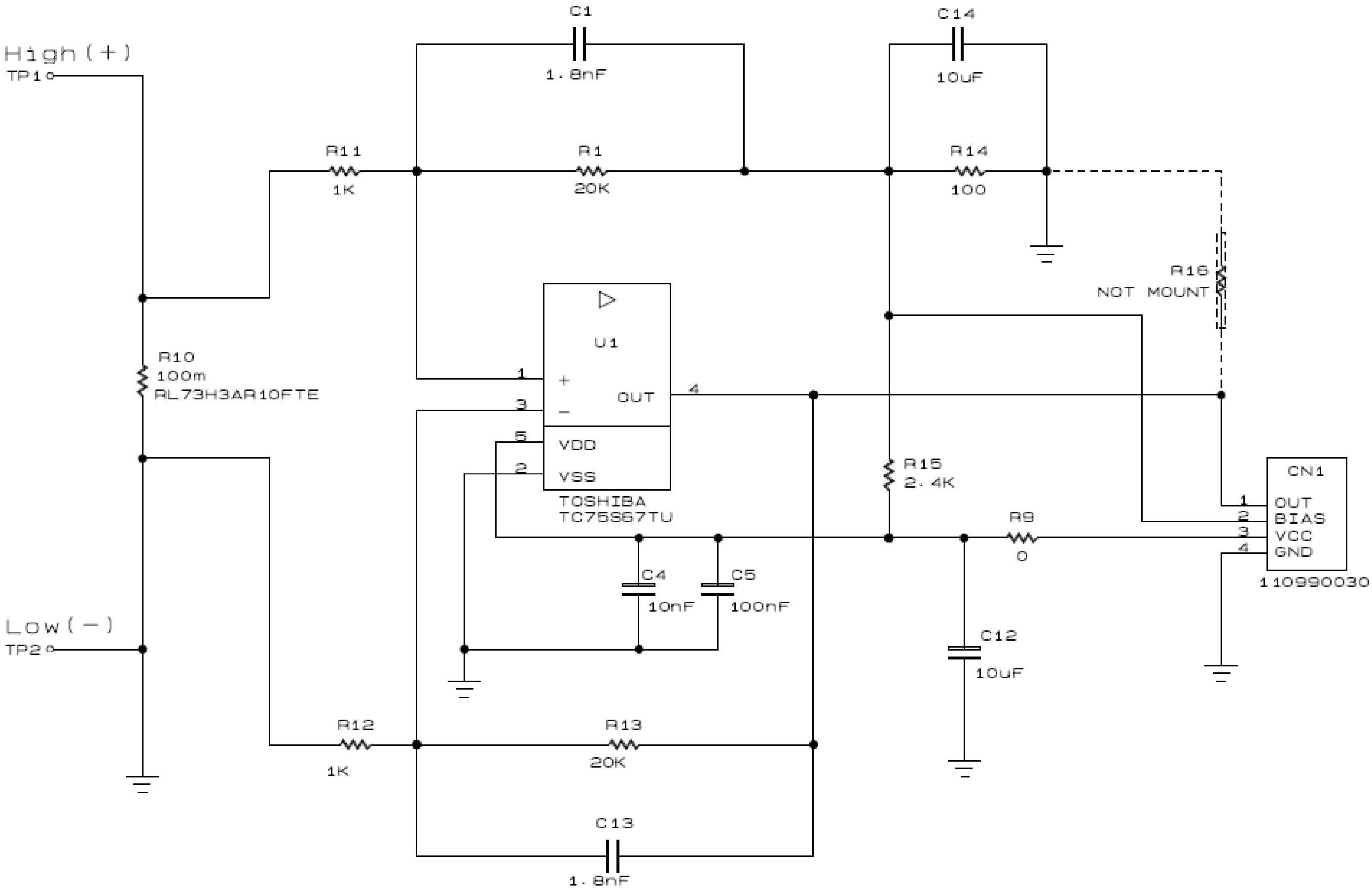


Fig. 3.1 Current Sensor Circuit Diagram

## 3.2. Bill of Materials

Table 3.1 Bill of Materials

| Item | Parts | Q'ty | Value | Part name | Manufacturer | Description | Package Name | Standard dimensions mm (inch) | Mounting |
|---|---|---|---|---|---|---|---|---|---|
| 1 | U1 | 1 | - | TC75S67TU | TOSHIBA | Operational amplifier | SOT-353F | 2.0×2.1×0.7 | |
| 2 | C1, C13 | 2 | 1800 pF | | | Ceramic<br>50 V, ±10 % | | 1.0×0.5 (0402) | |
| 3 | C4 | 1 | 10 nF | | | Ceramic<br>25 V, ±10 % | | 1.0×0.5 (0402) | |
| 4 | C5 | 1 | 100 nF | | | Ceramic<br>16 V, ±10 % | | 1.0×0.5 (0402) | |
| 5 | C12, C14 | 2 | 10 μF | | | Ceramic<br>25 V, ±10 % | | 2.0×1.2 (0805) | |
| 6 | R1, R13 | 2 | 20 kΩ | | | 100 mW, ±1 % | | 1.0×0.5 (0402) | |
| 7 | R9 | 1 | 0 Ω | | | 1 A | | 1.0×0.5 (0402) | |
| 8 | R10 | 1 | 100 mΩ | RL73H3A R10FTE | TE connectivity | Shunt resistor<br>1 W, ±1 % | | 6.4×3.2 (2512) | |
| 9 | R11, R12 | 2 | 1 kΩ | | | 100 mW, ±1 % | | 1.0×0.5 (0402) | |
| 10 | R14 | 1 | 100 Ω | | | 100 mW, ±1 % | | 1.0×0.5 (0402) | |
| 11 | R15 | 1 | 2.4 kΩ | | | 100 mW, ±1 % | | 1.0×0.5 (0402) | |
| 12 | R16 | 1 | | | | | | 1.0×0.5 (0402) | Not mounted<br>Dummy load |
| 13 | CN2 | 1 | - | 110990030 | Seeed Studio | Grove connector<br>4 pins/straight | | 10×5.1×8.1 | |

### 3.3. Board Pattern Drawing

This board consists of both top and bottom sides. The parts mounting side is top side.

<Top Side (Parts Mounting Side)>

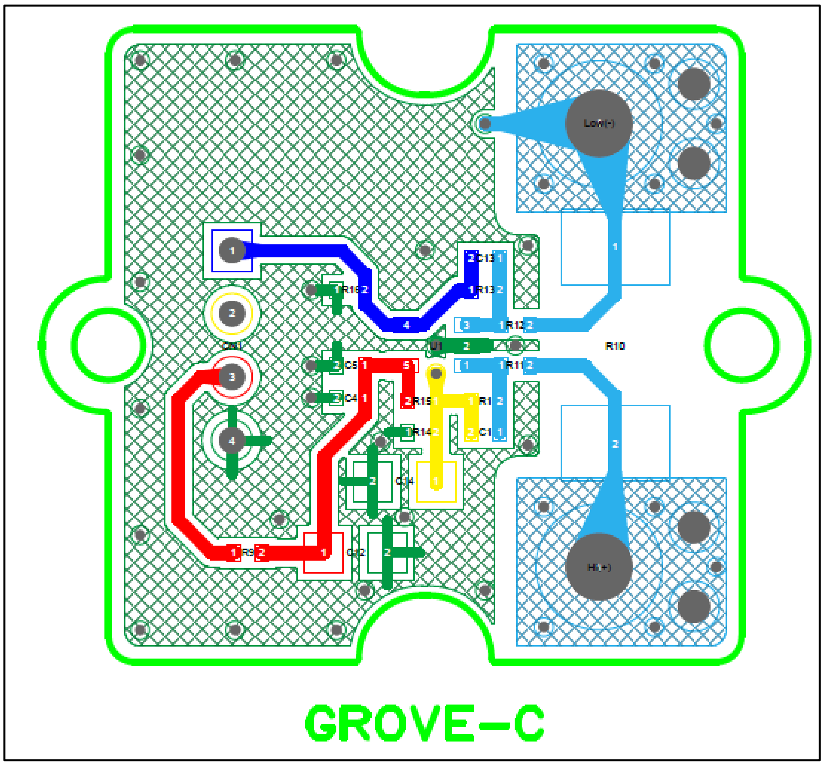


Fig. 3.2 Board Pattern

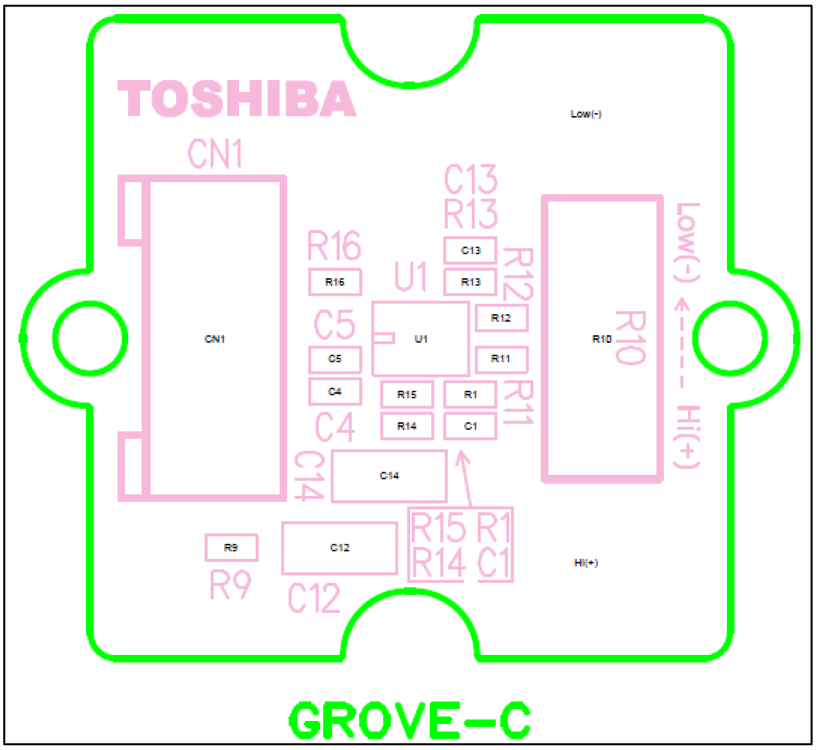


Fig. 3.3 Substrate Silk

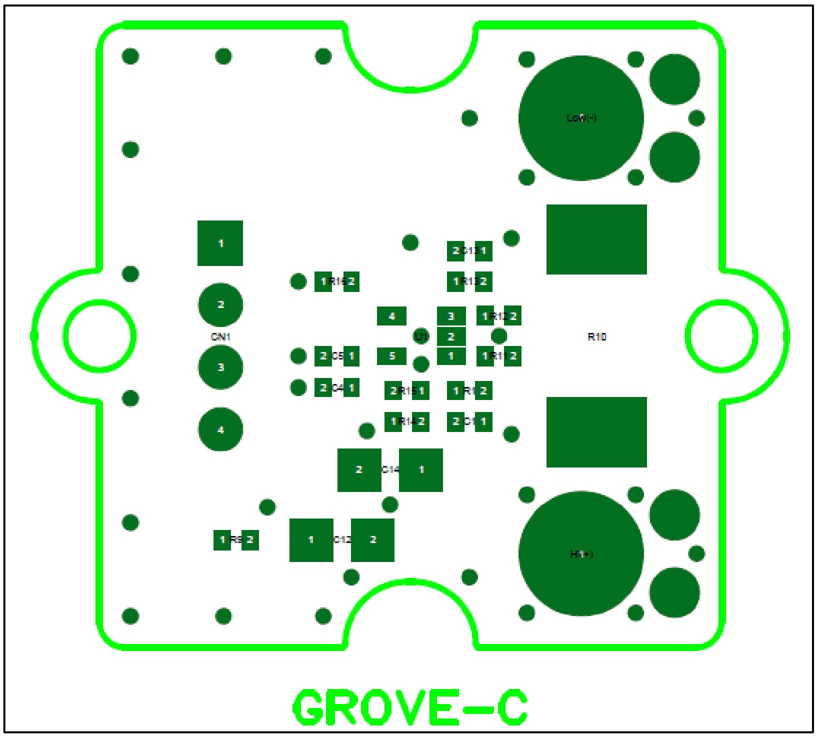


Fig. 3.4 Substrate Solder

<Bottom Side>

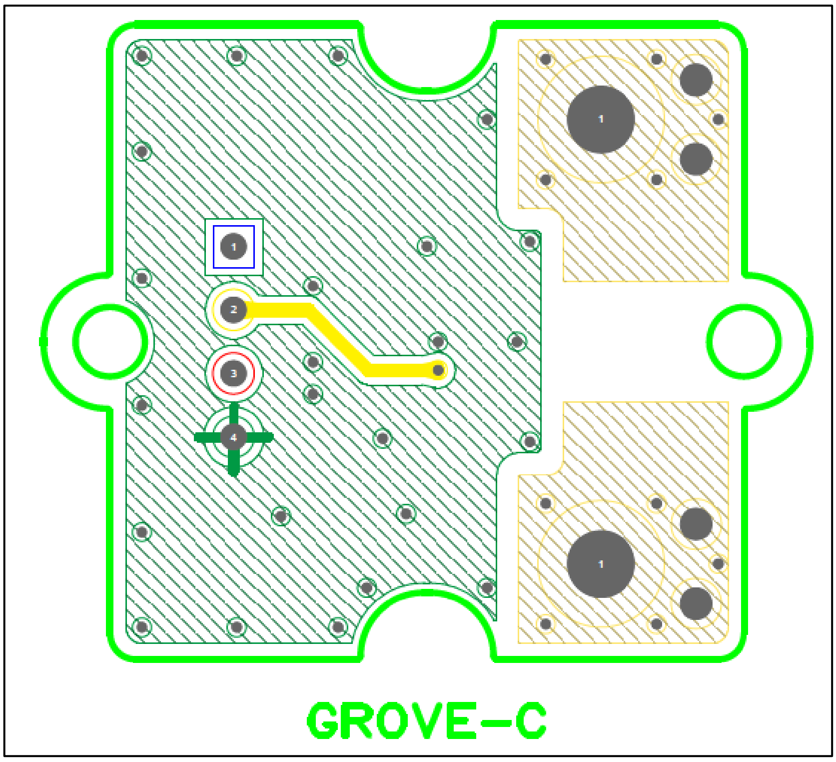


Fig. 3.5 Board Pattern

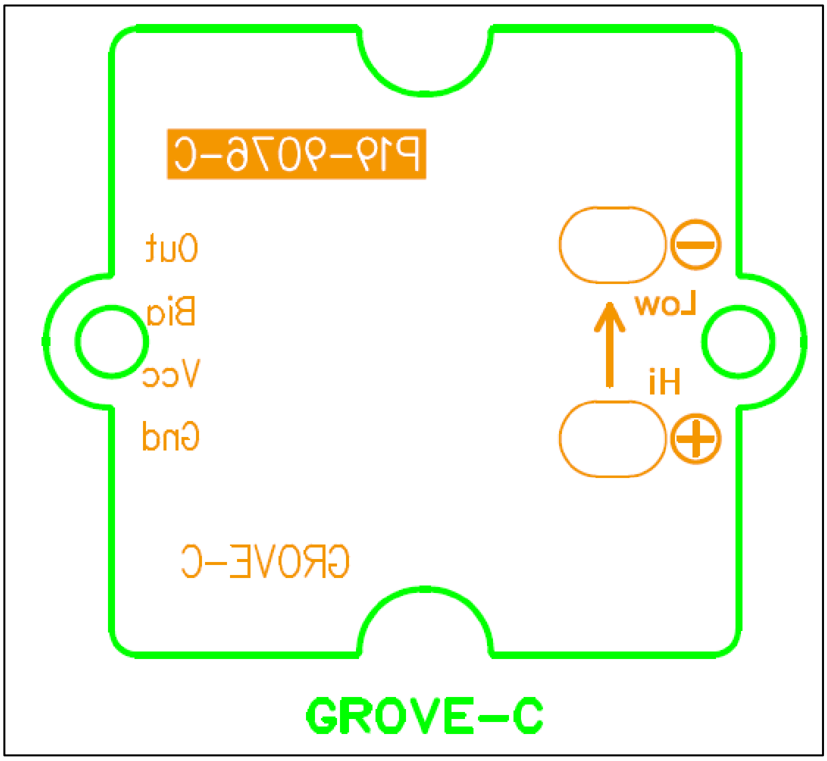


Fig. 3.6 Substrate Silk

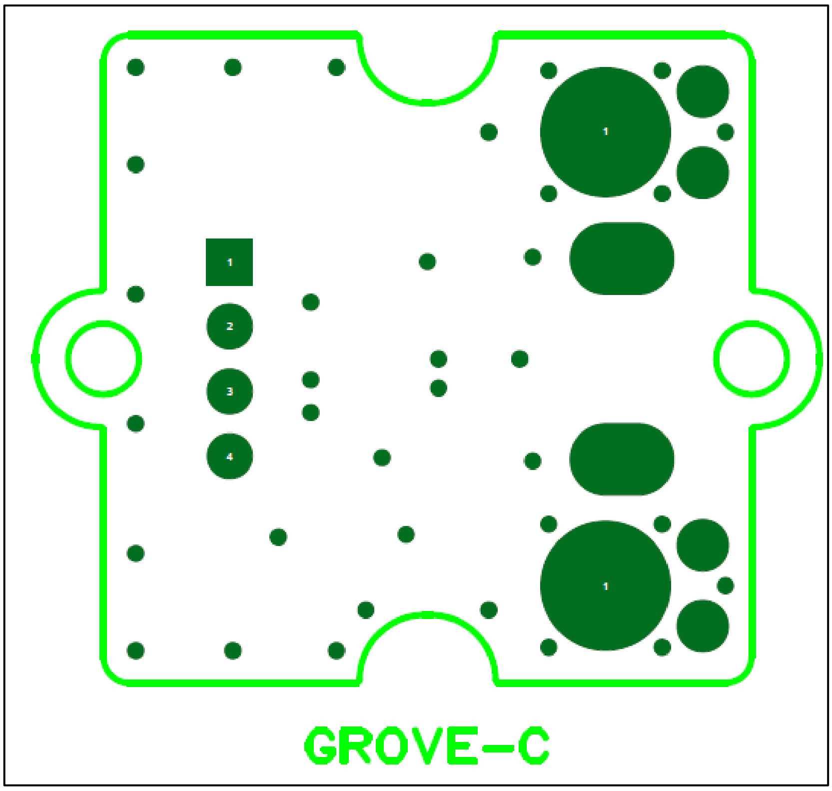


Fig. 3.7. Substrate Solder

# 4. Operation Procedure

## 4.1. Arduino and Processing

Arduino is a palm-sized one-board microcontroller. The microcontroller is selected as the control microcontroller for this reference design because it is generally available on the market and can be easily got, and if the program is transferred once, the sensor can be operated without a PC. Use the Processing to display the measurement results on the PC-screen.

This reference design provides Arduino operating program and a Processing program that displays the status of measurements. To run this program, you must install Arduino IDE and Processing 3 on your PCs. Both software are available free of charge on their official sites. Download the software and install it on your PC in advance. These software are also needed to edit each program. These programs are called "sketches" in Arduino, Processing.

Moreover, in the case of Windows10, a display window for result of Processing may not start. In such a case, it is necessary to change the configuration file of initial value that generated automatically at the first time start-up of Processing. Since a solution change with PCs, please implement a suitable solution with reference to Web etc.

Refer to the Commercial Instructions for more information on Arduino and Processing.

## 4.2. Connecting to Arduino

Fig. 4.1 shows an example of connecting to Arduino.

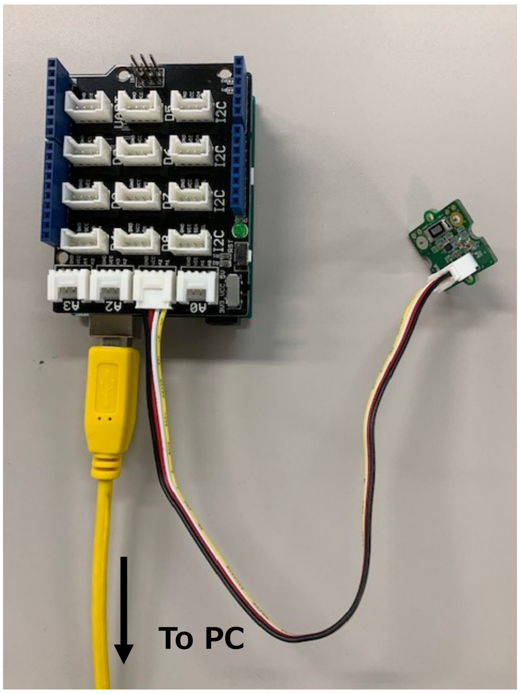


**Fig. 4.1 Connection to Arduino**

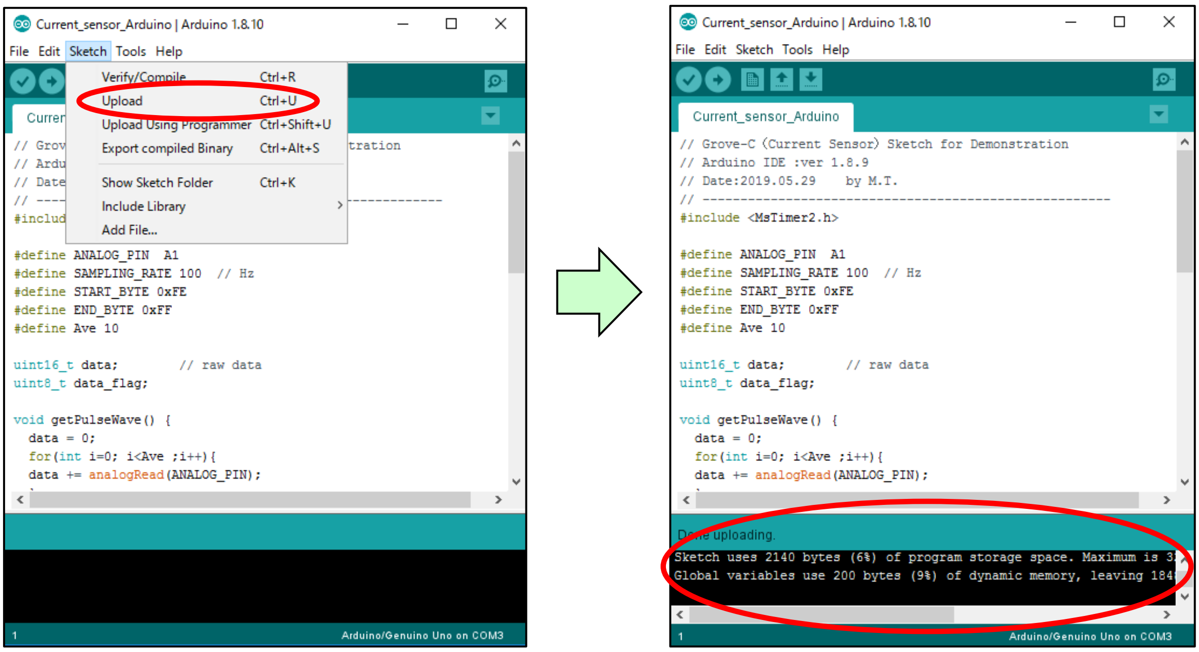
Arduino is used with ”seeed studio Base Shield”. The connection port of the base shield to the sensor is connected A1 terminal. Connect the base shield and the PC with a USB cable.

## 4.3. Start and Stop

When the compressed file "RD161-SKETCH-01_E.zip" of the sketch prepared for this sensor is downloaded from the following link and decompressed in an appropriate place on the PC, the folder containing the two files "Current_sensor_Arduino.ino" and "Current_sensor.pde" and the usage convention is created. Save the file as is.

To download sketches → Click Here

Start the Arduino IDE and select “File” → “Open” to open the saved Current_sensor_Arduino.ino file. The window shown on the left of Fig. 4.2 opens separately from the window opened at startup. Select “Sketch” → “Upload” to start compiling the files and write the sketch to the Arduino after compiling. When writing is completed successfully, a message appears at the bottom of the window. The Arduino is now ready.

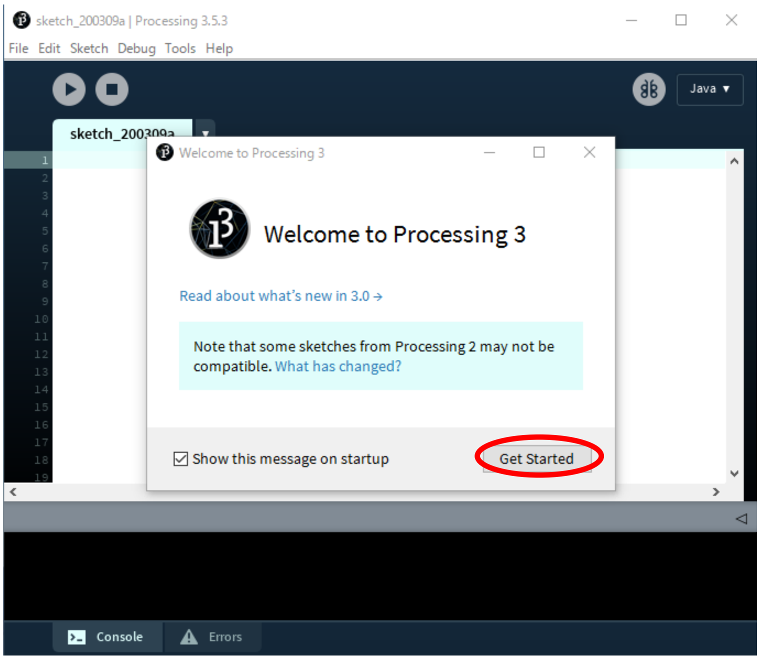


```
// Grove-C (Current Sensor) Sketch for Demonstration
// Arduino IDE :ver 1.8.9
// Date:2019.05.29    by M.T.
// -----------------------------------------------------
#include <MsTimer2.h>

#define ANALOG_PIN  A1
#define SAMPLING_RATE 100  // Hz
#define START_BYTE 0xFE
#define END_BYTE 0xFF
#define Ave 10

uint16_t data;        // raw data
uint8_t data_flag;

void getPulseWave() {
  data = 0;
  for(int i=0; i<Ave ;i++){
  data += analogRead(ANALOG_PIN);
```

```
Done uploading.
Sketch uses 2140 bytes (6%) of program storage space. Maximum is 3
Global variables use 200 bytes (9%) of dynamic memory, leaving 184
```

**Fig. 4.2 Arduino IDE Window**

Then start the Processing 3. When you start the Processing 3, the window shown in Fig. 4.3 opens. Click Get Started at the bottom right of the child window. Then, select File → Open to open the saved Current_sensor.pde file.



Welcome to Processing 3

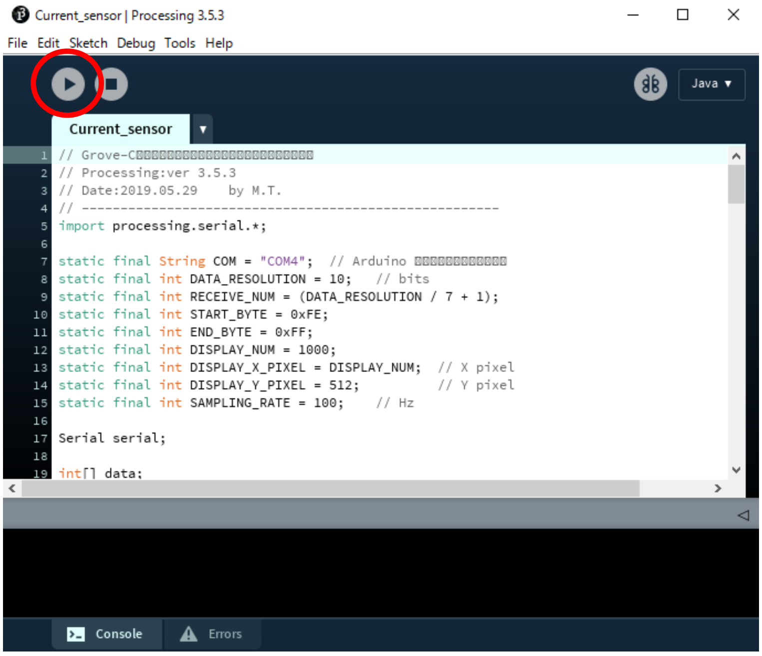
Read about what's new in 3.0 →

Note that some sketches from Processing 2 may not be compatible. What has changed?

☑ Show this message on startup

Fig. 4.3 Startup window of Processing 3

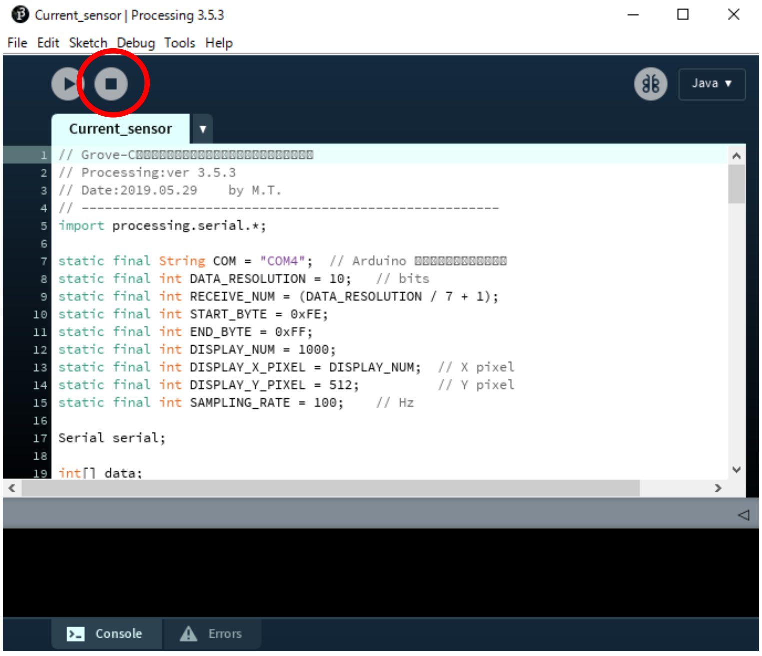
The window shown in Fig.4.4 opens separately from the window opened at startup. Click the operation button (red circle) here to open the result display window and start the measurement.



```
// Grove-C□□□□□□□□□□□□□□□□□□□□□□□□
// Processing:ver 3.5.3
// Date:2019.05.29    by M.T.
// -------------------------------------------------------
import processing.serial.*;

static final String COM = "COM4";  // Arduino □□□□□□□□□□□□
static final int DATA_RESOLUTION = 10;   // bits
static final int RECEIVE_NUM = (DATA_RESOLUTION / 7 + 1);
static final int START_BYTE = 0xFE;
static final int END_BYTE = 0xFF;
static final int DISPLAY_NUM = 1000;
static final int DISPLAY_X_PIXEL = DISPLAY_NUM;  // X pixel
static final int DISPLAY_Y_PIXEL = 512;          // Y pixel
static final int SAMPLING_RATE = 100;    // Hz

Serial serial;

int[] data;
```

Fig. 4.4 Processing Measurement Start Window

Click the stop button (red circle in Fig. 4.5) on this screen to finish the measurement. The Result View window closes and the measurement ends. Then close the open windows sequentially.



```
// Grove-C▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯▯
// Processing:ver 3.5.3
// Date:2019.05.29    by M.T.
// -----------------------------------------------------
import processing.serial.*;

static final String COM = "COM4";  // Arduino ▯▯▯▯▯▯▯▯▯▯▯▯
static final int DATA_RESOLUTION = 10;   // bits
static final int RECEIVE_NUM = (DATA_RESOLUTION / 7 + 1);
static final int START_BYTE = 0xFE;
static final int END_BYTE = 0xFF;
static final int DISPLAY_NUM = 1000;
static final int DISPLAY_X_PIXEL = DISPLAY_NUM;  // X pixel
static final int DISPLAY_Y_PIXEL = 512;          // Y pixel
static final int SAMPLING_RATE = 100;    // Hz

Serial serial;

int[] data;
```

**Fig. 4. 5 Processing Measuring Completion Window**

You can pause the measurement by clicking on the result display window while the measurement is being performed. At this time, the result display window is not closed and the measurement waveform remains stopped. To restart the measurement, click on the window again.

## 4.4. Zero Point Correction Method

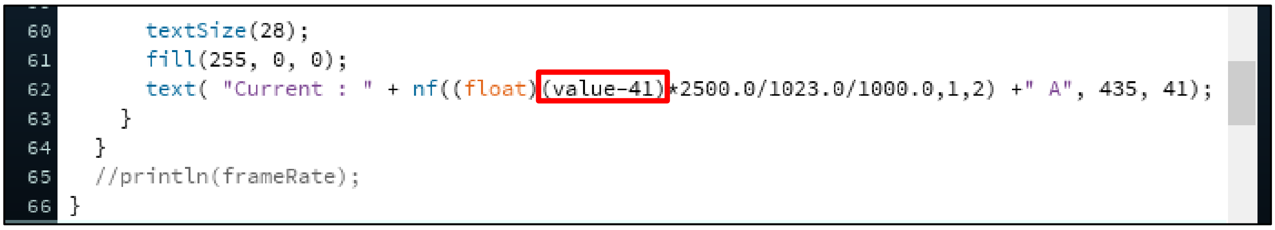
TC75S67TU may have input-offset voltages of 0.5 mV, typical, and up to 3 mV according to the product specification. Since this is the offset voltage multiplied by the gain on the output, a maximum output offset voltage of 60 mV may be generated with this sensor with a gain setting of 20 times (26 dB), which causes a zero point deviation and causes an error.

For example, if there is an offset voltage of 0.5 mV in terms of input, this corresponds to a current of 5 mA with a 100 mΩ shunt resistor, so the measurement result will show 0.01 A, even though no current actually flows.

This zero shift can be corrected by software. This section explains how to correct a zero shift.

This current sensor calculates the current value from the voltage drop of the shunt resistor, but for the purpose of improving the current detection accuracy around 0 A and GND sensing, the input terminal has been biased at 200 mV to raise DC voltage. This value is subtracted when calculating the current value. The zero shift by the offset of the op-amp is compensated by changing this part.

The relevant part is the 62nd line (Fig. 4.6) of the sketch of Processing prepared in this reference design.



```
60      textSize(28);
61      fill(255, 0, 0);
62      text( "Current : " + nf((float)(value-41)*2500.0/1023.0/1000.0,1,2) +" A", 435, 41);
63    }
64  }
65  //println(frameRate);
66 }
```

**Fig. 4.6 Line 62 of Processing Sketch**

In the red box shown in Fig. 4.6, the input voltage to Arduino is calculated by counting the LSBs (Least Significant Bit) of the input A/D converter, and "value" is the result of measuring the output voltage of the operational amplifier including the offsets. The bottom-up voltage is subtracted from this point to cancel.

Since Arduino input A/D converter has 10 bits, the voltage $V_{LSB}$ per 1 count of LSB is as follows.

$$V_{LSB} = \frac{V_{CC}}{2^{10}-1} = \frac{5}{1023} \cong 0.00488 = 4.88 \ \ (mV) \qquad \cdots\cdots \ (4.1)$$

The denominator in this equation subtracts 1 from $2^{10}$, because 0 is the first count.

If the output offset voltage is $V_{OS}$, the number of offset voltages counted by LSBs (the number subtracted from "value") x is obtained by the following equation 4.2.

$$x = \left\lceil \frac{V_{OS}}{V_{LSB}} - 0.5 \right\rceil = \left\lceil \frac{V_{OS}}{\left(\frac{V_{CC}}{2^{10}-1}\right)} - 0.5 \right\rceil = \left\lceil \frac{V_{OS} \times (2^{10}-1)}{V_{CC}} - 0.5 \right\rceil = \left\lceil \frac{V_{OS} \times 1023}{5} - 0.5 \right\rceil \quad \cdots\cdots \ (4.2)$$

Since the count number is an integer value that is closest to $V_{OS}$ divided by $V_{LSB}$, Equation 4.2 performs an operation (ceiling function) that gives the smallest integer that is greater than or equal to the value obtained by subtracting 0.5 from the result of the division. The symbol “⌈ ⌉” in the equation indicates the ceiling function.

When there is no offset of the operational amplifier, $V_{OS}$ is 0.2 V. Therefore, the count number at this time is 41 as shown in the equation 4.3 below.

$$x = \left\lceil \frac{0.2 \times 1023}{5} - 0.5 \right\rceil = \lceil 40.92 - 0.5 \rceil = 41 \qquad \cdots\cdots \ (4.3)$$

Processing sketches provided in this reference design defaults to 41. When there is a zero point shift, please make adjustments according to the following. Sketches can be edited and saved on Processing.

The following explains the procedure by taking the case where zero point misalignment of 0.01 A occurs as an example.

Since the voltage drop of the shunt resistor (100 mΩ=0.1 Ω) generated by the current equal to the displayed deviation is considered to be the input-offset voltage $V_{IO}$ of the op-amp, $V_{IO}$ is assumed to be 1 mV as shown in the equation 4.4.

$$V_{IO} = 0.01 \times 0.1 = 0.001 = 1 \ (mV) \qquad \cdots\cdot \ (4.4)$$

At this time, the output offset voltage $V_{OS}$ of the op-amp is the voltage which added 0.2 V for a bottom raising to the voltage which increased $V_{IO}$ 20 times, and is obtained as shown in the equation 4.5 below.

$$V_{OS} = 0.2 + 0.001 \times 20 = 0.22 \ (V) \qquad \cdots\cdot \ (4.5)$$

Assign this to the equation 4.2 to calculate the count.

$$x = \left\lceil \frac{0.22 \times 1023}{5} - 0.5 \right\rceil = \lceil 45.012 - 0.5 \rceil = \lceil 44.512 \rceil = 45 \qquad \cdots\cdot \ (4.6)$$

Change Processing sketch line 62 (Fig 4.6) as follows:

```
text( "Current : " + nf((float)(value-45)*2500.0/1023.0/1000.0,1,2) +" A", 435, 41);
```

In Processing sketch of this reference design, the smallest digit of the result display is larger than the resolution determined by the LSB. Therefore, the zero point deviation may not be eliminated. If this happens, adjust the value one by one while viewing the actual result display.

## 4.5. Precautions for Evaluation

- The resolution of this current sensor is approximately 2.4 mA.
- Although the shunt resistor of the current sensor is set to a minute resistance value in consideration of heat generation, it may become hot if the current continues to flow for a long time. Be careful not to touch the board directly in such a case as this may cause burns.
- The current sensor in this guide is designed to be connected to the low (GND) side of the load with the shunt resistor's Low (-) terminal grounded. It cannot be used by connecting to the high (power supply) side.
- When this current sensor is connected, it may affect the start and stop sequence of the equipment that is the load.

# 5. Current Measurement Results

In Processing, the current calculated from the measured value is displayed.

A measurement result display window when a DC power supply is connected to shunt resistor and turned on is shown below.

Fig.5.1 shows a waveform when current is set as 0.10 A, Fig.5.2 shows a waveform when it is set as 1.50 A. The displayed current value shows the value after power ON.

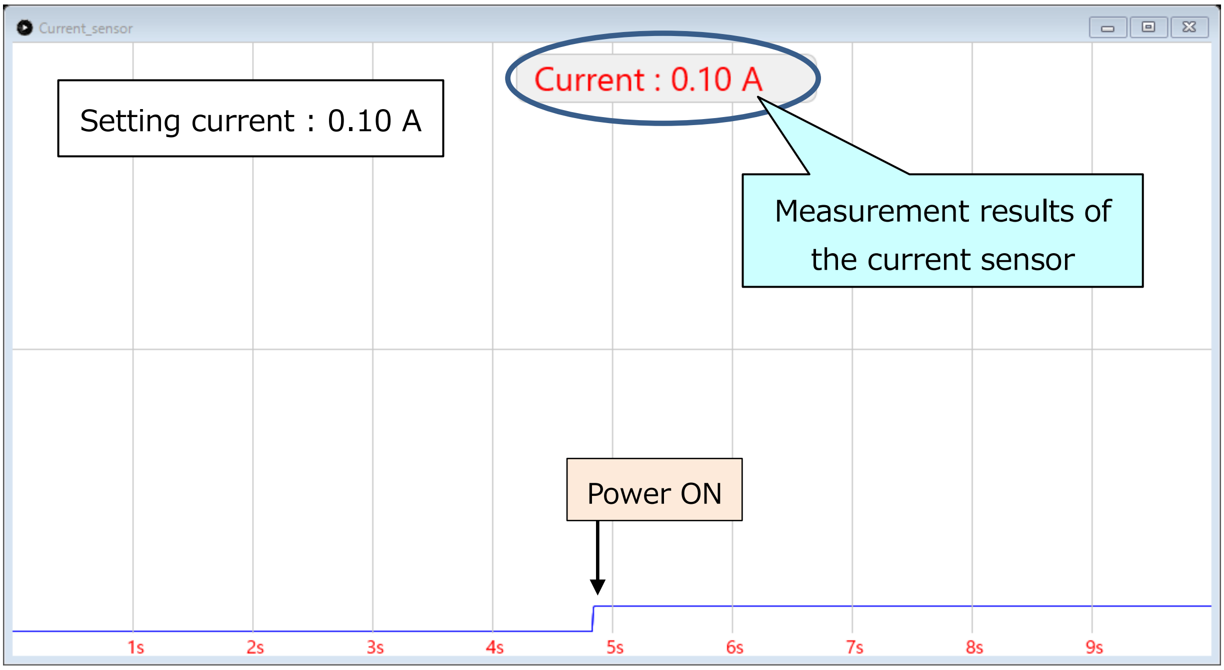


Fig. 5.1 Measurement Result Indication by Processing (1)

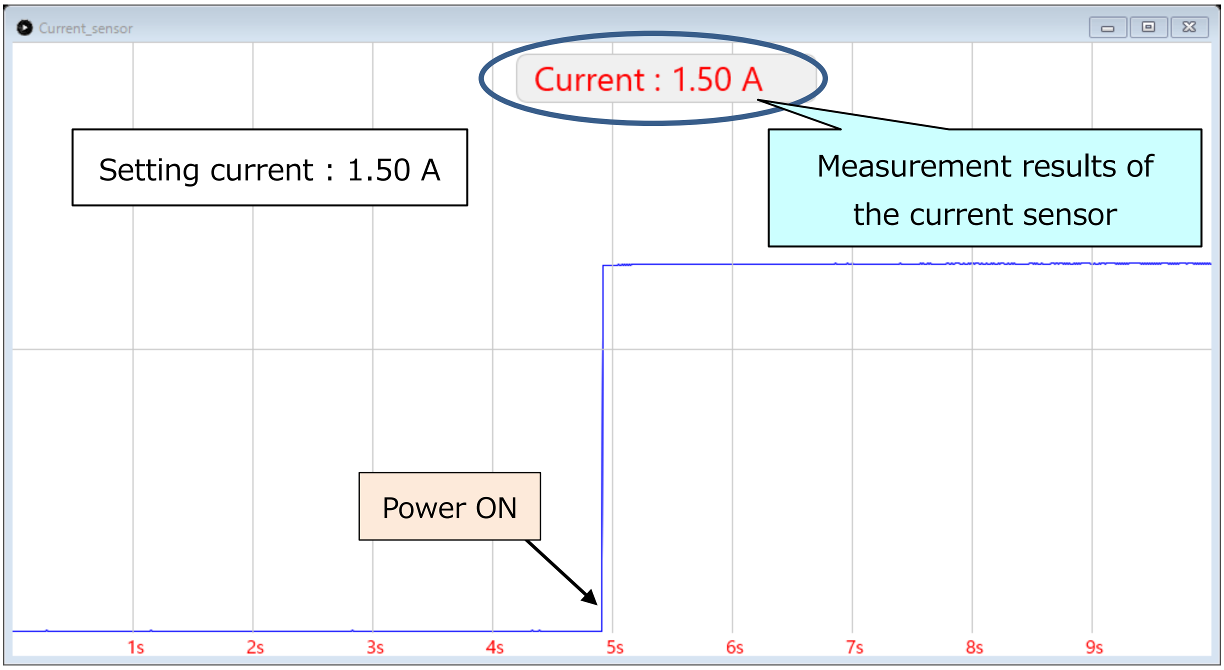


Fig. 5.2 Measurement Result Indication by Processing (2)

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