

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

## Design guide

### RD160-DGUIDE-01

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#### Overview

This Design Guide (hereinafter referred to as “this guide”) describes designing pyroelectric infrared human sensors using low-noise op-amp TC75S67TU. Human sensors are widely used in security lights, toilets, entrance lights, automatic faucets, etc. Infrared rays, ultrasonic waves, and visible light are used to detect human locations. This guide describes examples of applications of low-noise op-amp TC75S67TU using human sensors that use pyroelectric elements to detect infrared rays.

## TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

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## 1. Introduction

Op-amps are still used in a variety of situations even today in the digital age, and a particularly important application is their use in a variety of sensors.

There are various types of information that can be obtained from nature, such as sound and light, and there are various types of sensor elements accordingly. Generally, the output signal from a sensor element is very weak, and it is hard to handle as it is, so in most cases it is amplified and processed.

Op-amps are used for this amplification. In addition to amplification, op-amps are used for filters and I-V conversion in various sensors, and it is not an overstatement to say that most modern electronic devices cannot be realized without an op-amp.

Noise characteristics are important in applications with these sensors. If the op-amp itself is noisy, critical sensor signals may be masked by noise, resulting in a decrease in detection sensitivity or false detection, preventing the desired sensing performance from being attained. Therefore, the operational amplifiers used in such applications require low noise levels.

In order to meet these requirements, Toshiba have developed an operational amplifier TC75S67TU with a low noise level of 6 nV/ $\sqrt{\text{Hz}}$  (@f=1 kHz,  $G_V=40$  dB, typical).

This Design Guide describes designing pyroelectric infrared human sensors using TC75S67TU. For more information on TC75S67TU, refer to the data sheet of the link destination below.

To download the datasheet for TC75S67TU →

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## 2. Circuit Design

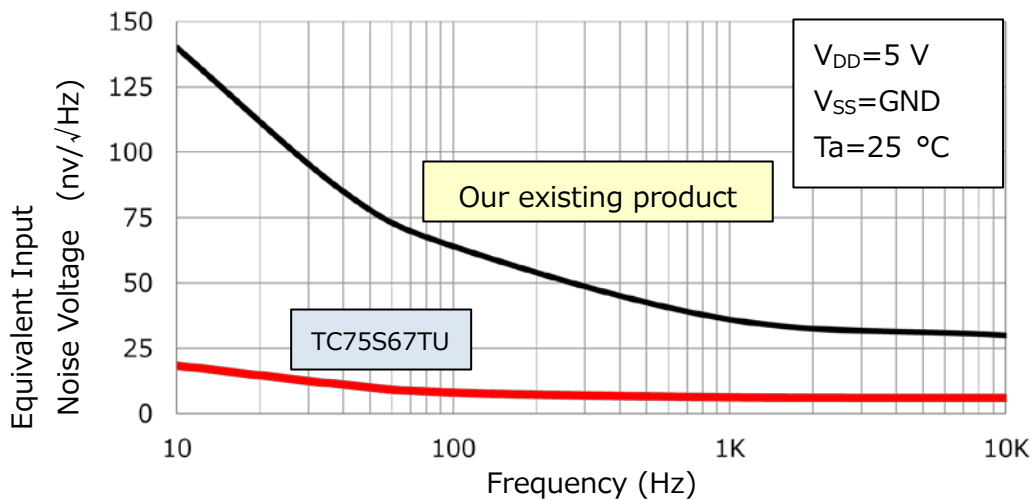
### 2.1. About low-noise op-amp TC75S67TU

The low-noise op-amp TC75S67TU used in the pyroelectric infrared sensor described in this guide took measures from both the circuits and manufacturing processes, and succeeded in reducing the noise level to a greater extent than our existing products.

Generally, noise has 2 ways on the frequency component contained point of view:

1. 1/f noise which is distributed in the low frequency region
2. White noise which is distributed in the wide region from low frequency to high frequency.

TC75S67TU realizes low noise levels such as 16 nV/ $\sqrt{\text{Hz}}$  (@f=10 Hz) in the low frequency region where 1/f noise is mainly used, and 6 nV/ $\sqrt{\text{Hz}}$  (@f=1 kHz, typ.) in the region where white noise is mainly used. Fig.2.1 shows a graph comparing the noise level-frequency characteristics of TC75S67TU and our existing product.



**Fig.2.1 TC75S67TU Equivalent Input Noise Voltage-Frequency Characteristics**

As shown in Fig.2.1, the noise of TC75S67TU is greatly improved compared to existing products, making it an optimum op-amp for amplifying the signal of sensors that handle weak signals. In addition to this noise characteristic, TC75S67TU has a very small input bias current of 1 pA, and the offset voltage is also small.

For sensors that handle weak signals, the effect of the offset voltage is also large, which may cause deterioration of the sensor performance. Therefore, a resistor for offset correction may be required at the input terminals. Since the resistor generates thermal noise, the noise may deteriorate in this case. However, since the offset voltage is small for TC75S67TU, it is not necessary to add a resistor for offset compensation.

By using TC75S67TU with the above features, high-sensitivity and high-performance sensors can be designed.

Please also refer to the application notes below for more information on TC75S67TU noise.

To download the application notes on TC75S67TU noise →

[Click Here](#)

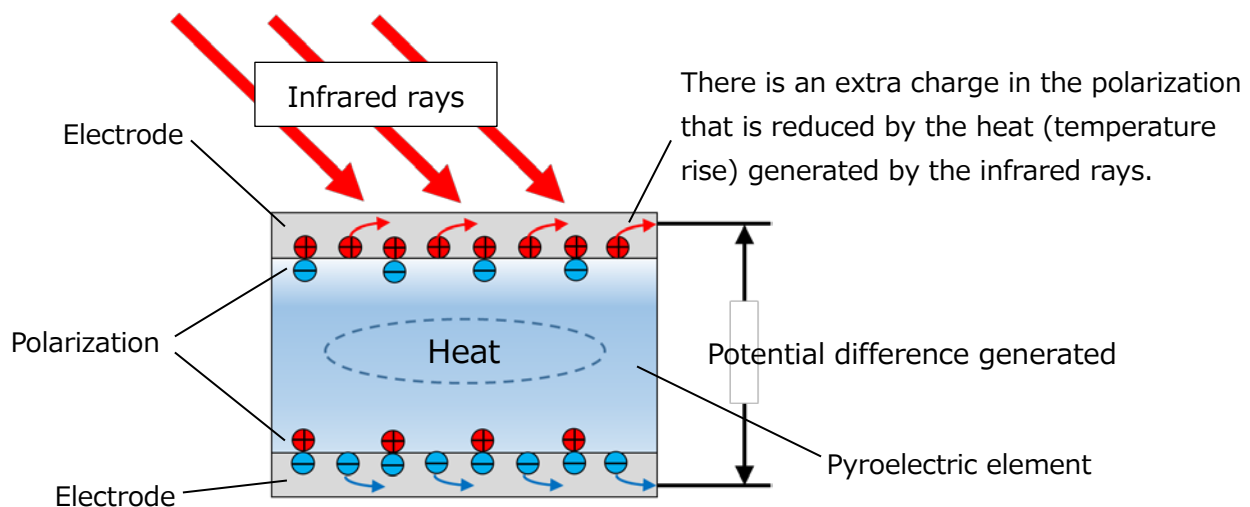
## 2.2. About Pyroelectric Infrared Sensors

There are two types of Infrared sensors:

1. Quantum sensors that utilize photovoltaic and other electrical phenomena due to light energy
2. Thermal sensors that utilize infrared temperature rise.

In the application circuits of this guide, pyroelectric elements belonging to the latter category are used. Pyroelectric elements are devices that detect infrared rays using a phenomenon in which electric charges are excited on the dielectric surface (pyroelectric effect) due to temperature changes. Although the response time is long, they are inexpensive.

The operation is explained with a schematic diagram of the pyroelectric element structure shown in Fig.2.2.

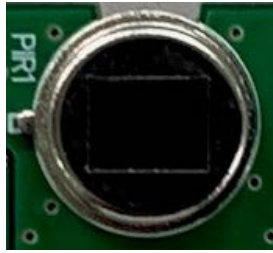


**Fig.2.2 Pyroelectric Element Structure Diagram**

Materials that exhibit pyroelectric effects include ferroelectric ceramics. These materials are normally polarized to the positive and negative sides, and are normally linked to the free charge in the electrode to cancel the charge. When infrared rays are irradiated here, the charge polarized by the heat generated inside the dielectric decreases, but the free charge cannot react as quickly as this polarization decreases, and a time lag occurs. During this period, extra charge is present in the electrode, and is observed as the potential difference between the electrodes. This series of functions is called the pyroelectric effect. The pyroelectric element measures this potential difference to detect infrared rays. Even when the irradiated infrared rays are blocked, reverse movement occurs, creating a reverse potential difference between the electrodes.

Pyroelectric infrared sensors detect the presence of objects emitting infrared radiation, such as humans, in this way, but as described, charges move in response to fluctuations in infrared radiation so that they cannot be detected without movement.

This time, we will use a Fresnel lens (condensing lens) attached to the pyroelectric infrared sensor IRA-S410ST01 manufactured by Murata Manufacturing. Fresnel lenses can be used by the same Murata Manufacturing IML-0687. The appearance of the sensor and Fresnel lens are shown in Fig. 2.3 and Fig.2.4.



**Fig.2.3 Pyroelectric Infrared Sensor  
(Murata Manufacturing IRA-S410ST01)**



**Fig.2.4 Fresnel Lens  
(Murata Manufacturing IML-0687)**

This sensor outputs low-frequency components of 0.34-23.4 Hz, which assume movements of humans and animals, contained in IRA-S410ST01's weak outputs, to the microcontroller using a 40-dB (101 times) non-inverting amplifier using TC75S67TU and a 26.6-dB (21.3 times) inverting amplifier for two-stage amplification.

This guide uses Arduino that allows the user to control the motion of the sensors as a whole and to view the measured results on the PC. If you prepare the software, you can use any other type of microcontroller. However, check the operation thoroughly.

### 2.3. Pyroelectric Infrared Human Sensor Specification

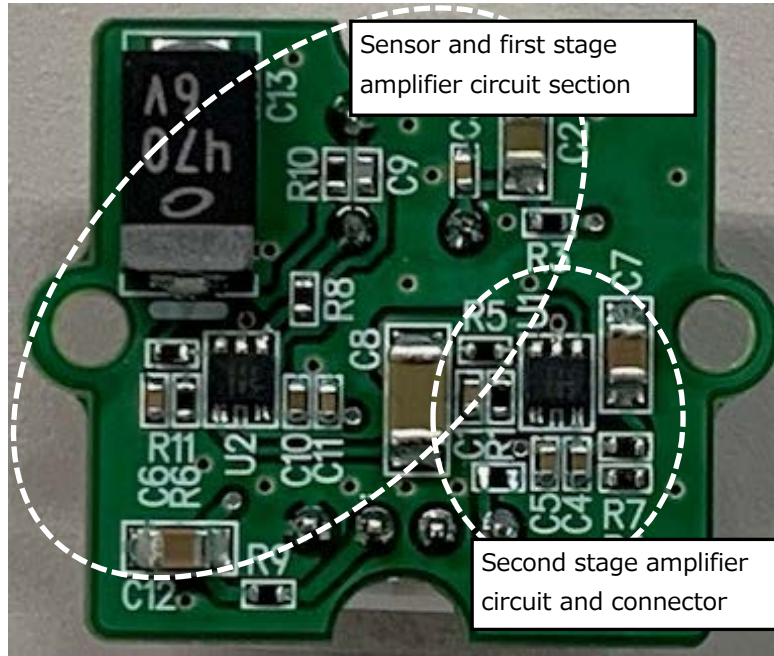
Table2.1 lists the specifications of this pyroelectric infrared human sensor.

**Table2.1 Pyroelectric Infrared Human Sensor Specifications**

Item	Specifications
Interface	Arduino connections
Control method	Control from Arduino and Shield Connected PCs
Power supply voltage	5 V from Arduino and Shield board
Detection range	Approx. 7 m
Onboard pyroelectric sensor	Murata Manufacturing IRA-S410ST01
Fresnel lens	Murata Manufacturing IML-0687
Onboard operational amplifier	Toshiba Device & Storage TC75S67TU

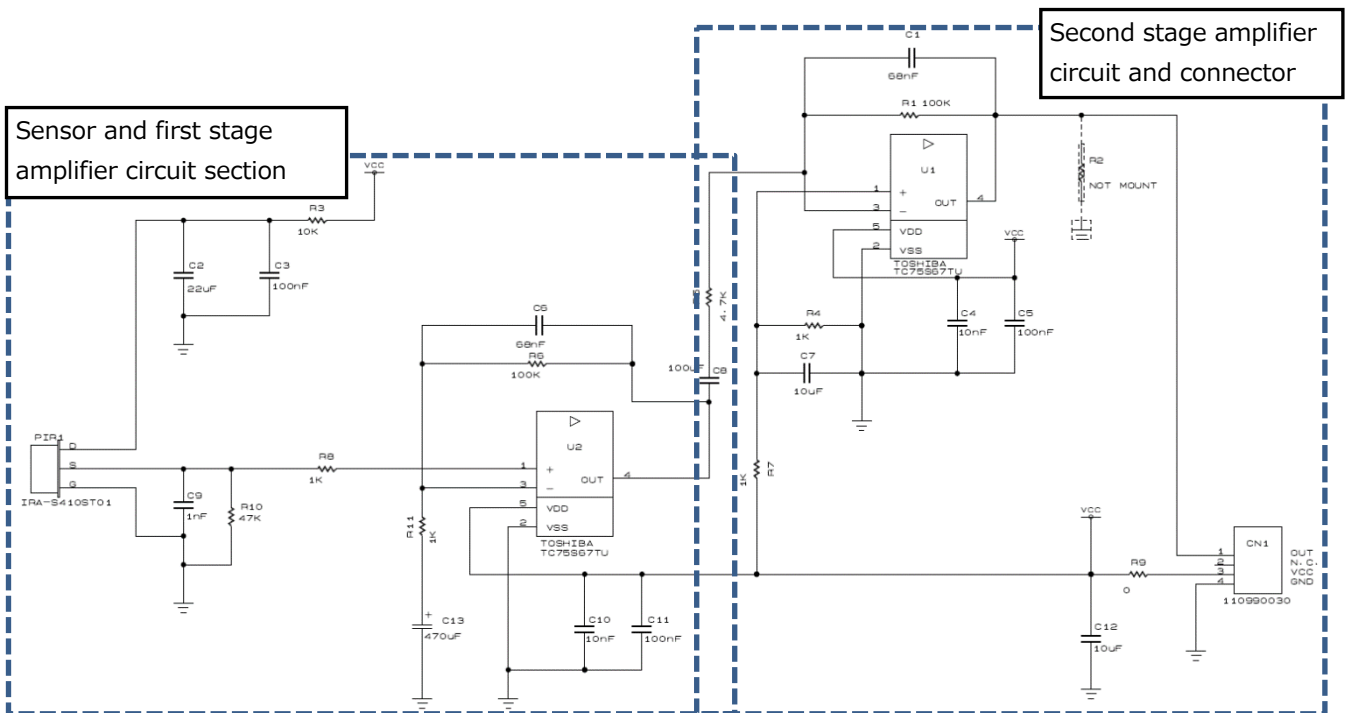
**2.4. Circuit Design of Pyroelectric Infrared Human Sensor**

Fig.2.5 shows a photograph of the pyroelectric infrared human sensor. This sensor consists entirely of one board. This section describes the settings and operations of the voltage amplification, filter, etc. for each part enclosed by the dotted line.



**Fig.2.5 Pyroelectric Infrared Human Sensor Board**

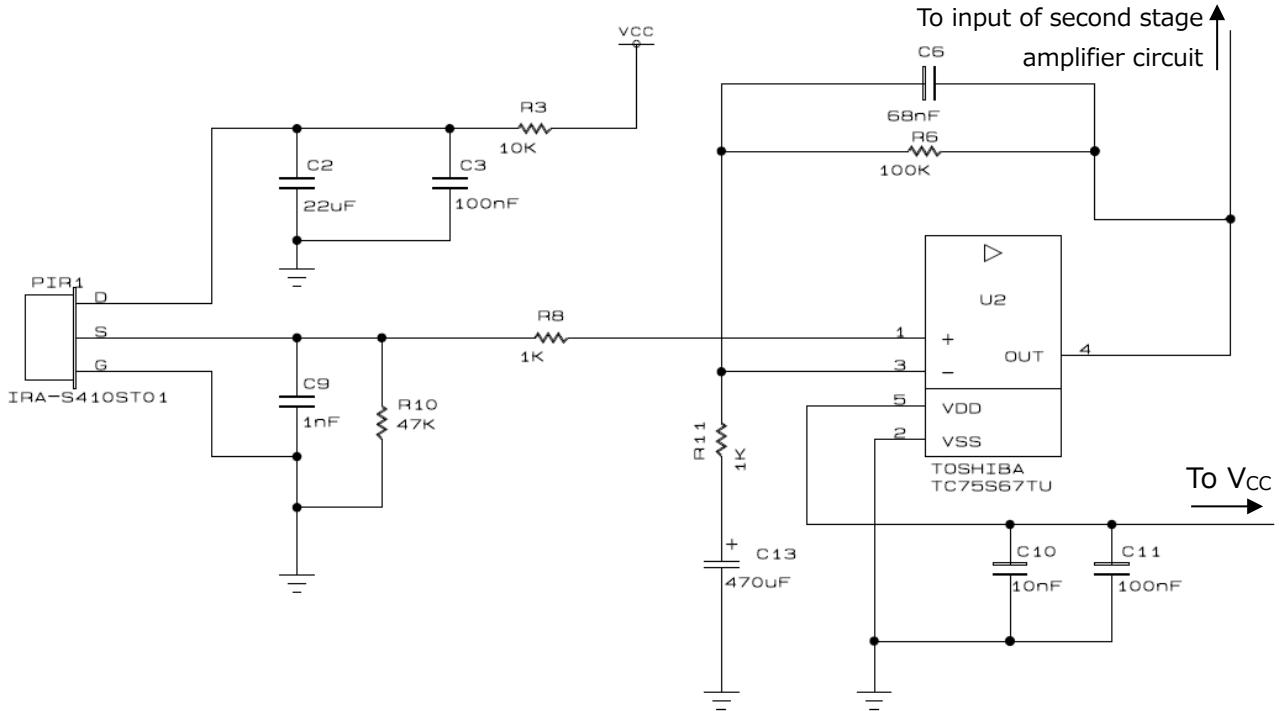
Fig.2.6 shows the overall schematics of this board.



**Fig.2.6 Pyroelectric Infrared Human Sensor Overall Schematics**

In this application circuit, two-stage configurations using two op-amps are each filtered to enhance the effect of eliminating unwanted frequency components. On the other hand, it is necessary to amplify about 60 to 70 dB in total from the output signal level of the pyroelectric sensor, so the gain is distributed to the form that the gain of the first stage is 40 dB and the remaining goes to second stage.

Fig.2.7 shows the pyroelectric infrared sensor and first stage amplifier circuit.



**Fig.2.7 Sensor and First-stage Amplifier Circuit Section**

R3 is inserted into the power line connected to the sensor, and a low-pass filter (LPF, cut-off frequency 0.72 Hz) is constructed together with C2 and C3 to enhance the effect of eliminating noise that is accumulated on the power supply.

In first stage of the amplifier circuit, the input signal is non-inverting amplified with a gain of 40 dB (101 times) set at R6 and R11 as described above, and the op-amp (U2) is biased by the source voltage of the pyroelectric infrared sensor IRA-S410ST01. Refer to IRA-S410ST1 datasheet for the values.

The feedback resistors also comprise a filter circuit, in which C11 and C13 are part of the high-pass filter (HPF) and R6 and C6 are part of the LPF. These filters are used as human sensors to eliminate low-frequency noise and high-frequency noise that are unwanted to detect human movement.

The cutoff frequency ( $f_{CH1}$ ) of the first stage HPF, the cutoff frequency ( $f_{CL1}$ ) of the LPF, and the gain ( $G_{V1}$ ) are calculated by the following equations.

$$f_{CH1} = \frac{1}{2 \times \pi \times R11 \times C13} = \frac{1}{2 \times \pi \times 1 \times 10^3 \times 470 \times 10^{-6}} \cong 0.34 \text{ Hz} \dots (2.1)$$

R11: 1 kΩ, C13: 470 μF



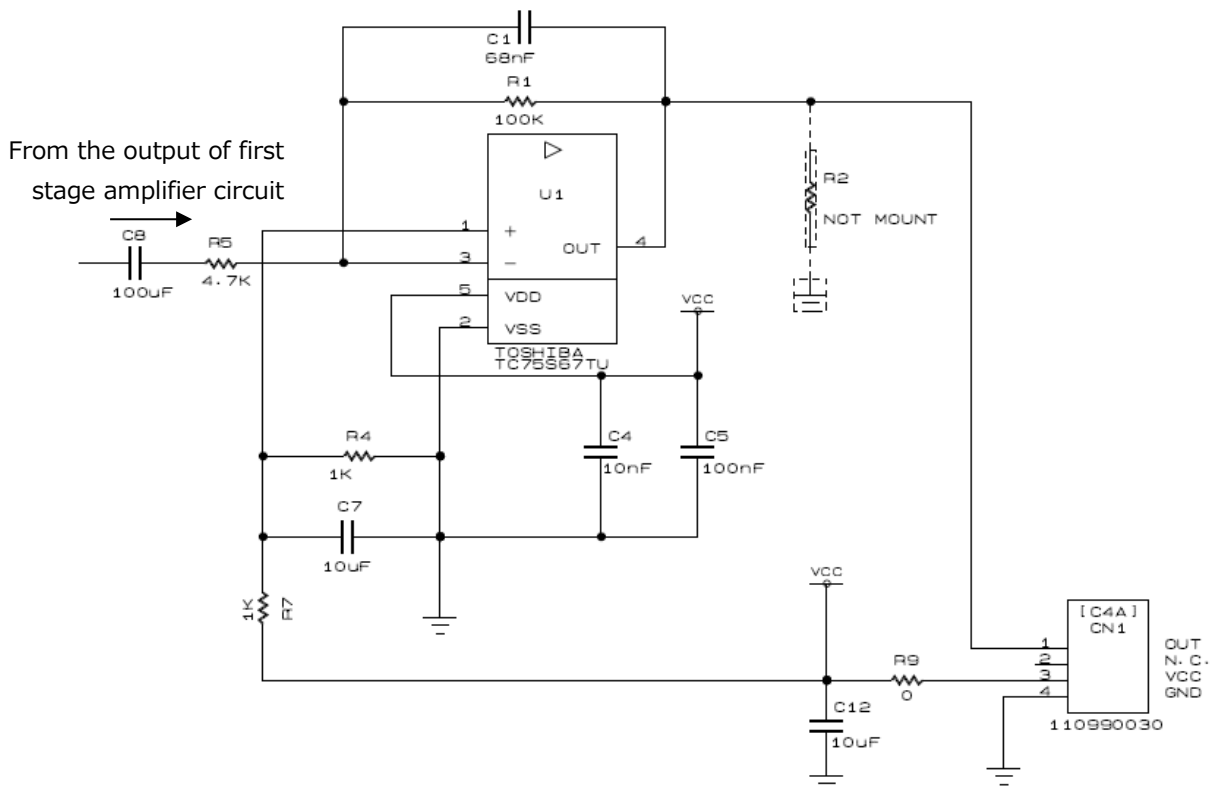
$$f_{CL1} = \frac{1}{2 \times \pi \times R6 \times C6} = \frac{1}{2 \times \pi \times 100 \times 10^3 \times 68 \times 10^{-9}} \cong 23.4 \text{ Hz} \quad \dots (2.2)$$

R6: 100 kΩ, C6: 68 nF

$$G_{v1} = \frac{R6 + R11}{R11} = \frac{100 \times 10^3 + 1 \times 10^3}{1 \times 10^3} = 101 \text{ (40 dB)} \quad \dots (2.3)$$

R6: 100 kΩ, R11: 1 kΩ

Fig.2.8 shows second stage amplifier circuit and connector.



**Fig.2.8 Second Stage Amplifier Circuit and Connector**

In second stage amplifier circuit, inverted amplification is performed, and the first output signal is input to the inverted input terminal IN (-) of the op-amp (U1). Gain is set to 21.3 times (26.6 dB) for R5 and R1. Since the op-amp (U1) is biased at a voltage (mid-point voltage) of  $V_{CC}/2$  obtained by dividing the power supply voltage  $V_{CC}$  by R4 and R7, the output signal amplitudes around the mid-point voltage. C7 is a bypass capacitor that removes the noise component from this bias voltage.

In second stage, as in the first stage, the filter is composed of a feedback path, with R5 and C8 being part of the HPF, and R1 and C1 being part of the LPF respectively. For both HPF and LPF, the cutoff frequency is set to the same value as for the first stage to enhance the effect of removing unwanted components. C8 also means the coupling capacitance of the first and second stage inputs with different bias voltages.

The cutoff frequency ( $f_{CH2}$ ) of the second stage HPF, the cutoff frequency ( $f_{CL2}$ ) of the LPF, and the gain ( $G_{V2}$ ) are calculated by following equations.

$$f_{CH2} = \frac{1}{2 \times \pi \times R5 \times C8} = \frac{1}{2 \times \pi \times 4.7 \times 10^3 \times 100 \times 10^{-6}} \cong 0.34 \text{ Hz} \quad \dots (2.4)$$

R5: 4.7 kΩ, C8: 100 μF

$$f_{CL2} = \frac{1}{2 \times \pi \times R1 \times C1} = \frac{1}{2 \times \pi \times 100 \times 10^3 \times 68 \times 10^{-9}} \cong 23.4 \text{ Hz} \quad \dots (2.5)$$

R1: 100 kΩ, C1: 68 nF

$$G_{v2} = -\frac{R1}{R5} = -\frac{100 \times 10^3}{4.7 \times 10^3} \cong -21 \quad (27 \text{ dB}) \quad \dots (2.6)$$

R1: 100 kΩ, R5: 4.7 kΩ

The total gain  $G_{VT}$  of the first and second stages combined is as follows.

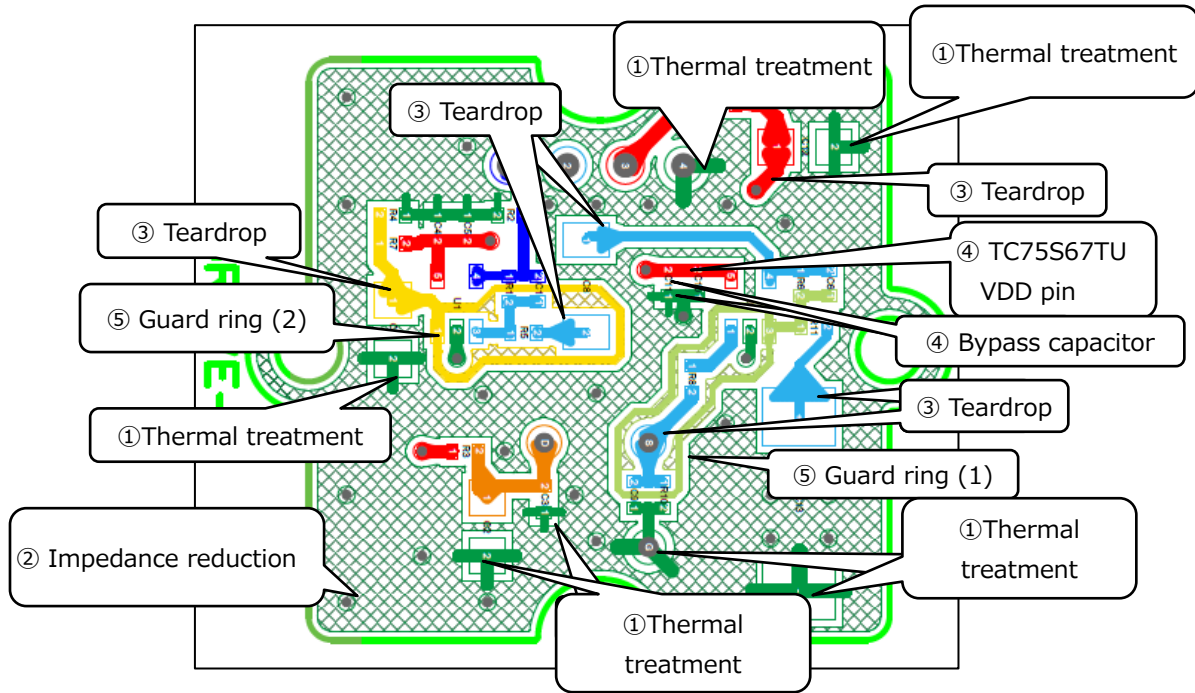
$$G_{vT} = G_{v1} \times G_{v2} = 101 \times 21 = 2121 \quad (67 \text{ dB}) \quad \dots (2.7)$$

Note that the power supply bypass capacitors of each op-amp are connected in parallel with two types of 10 nF and 100 nF with different capacitances. This is to effectively eliminate power supply noises in a wide frequency range by reducing the impedance in the lower frequency range below that of a 100 nF capacitor in the high frequency range of about 1 MHz or more with a 10 nF capacitor.

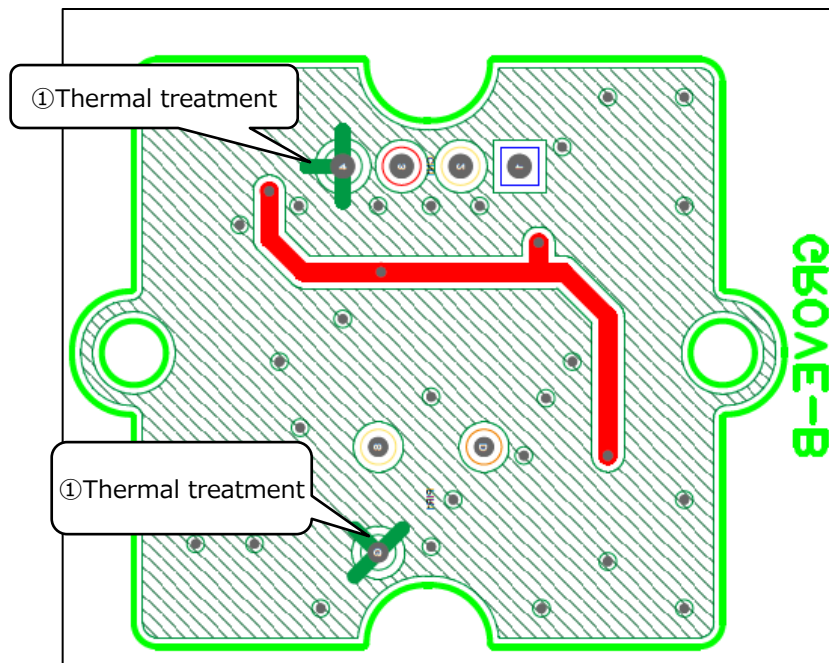
### 3. Board Design

#### 3.1. Example of Board Pattern

This board uses both front and back two-layer boards. Fig.3.1 shows the board pattern on the top side (component mounting surface) and Fig.3.2 shows the board pattern on the bottom side. Note on the Fig.3.1 and 3.2 show key care about. Section 3.2 shows for more detail.



**Fig.3.1 Board surface pattern**



**Fig.3.2 Board Back Pattern**

### 3.2. Key Care about on Board Design

#### ① Thermal treatment

In the example of the pattern, "Thermal treatment" is indicated by a cross or T-shape in the wiring from each pad to GND so that heat does not escape to a wide solid GND during soldering. This is to prevent the parts from overheating and deteriorating or breaking due to the heat escaping and the longer soldering time. Usually, the cross and T-shaped layout sections are buried in the solder after soldering, making it impossible to visually see them.

#### ② Impedance reduction

For a two-layer board, provide as many vias as possible between the front and back of the board to reduce the impedance between the front and back surfaces. This reduces the impedance of the entire GND and enhances the solid GND reference to prevent potential differences from occurring in the area and to prevent noise from spreading.

#### ③ Teardrop shape (see Fig.3.1)

In this example, the land and pad-to-wire connections are broadened to provide a tear drop (tear drop) configuration. This is intended to prevent the generation of singularities in the current at the pad area and to increase the connection strength between the pad and the wiring.

#### ④ Bypass Capacitor Location (see Fig.3.1)

Place a CR filter (LPF) to remove noise from the power supply near the power input to the board.

Also, place the D terminal of the pyroelectric type infrared sensor near the bypass capacitor of the power supply line to minimize the influence of noise from the power supply line.

In addition, to eliminate the noise superimposed on the power supply line, connect two bypass capacitors (100 nF and 10 nF) of the op-amp as close as possible to the power supply voltage pin of the corresponding device and to the power supply voltage line side.

Please select a capacitor with as small an ESR as possible. ESR=1  $\Omega$  or less is recommended.

#### ⑤ Guard ring (see Fig.3.1)

It is recommended to provide a guard ring around the area where minute signals are handled, such as the input part of the op-amp. In the pattern example in this guide, the IN (+) terminal, which is the input of the sensor signal of the first stage op-amp (U2), is guarded with an IN (-) potential. In addition, the second-stage op-amp (U1) guards around the IN (-) terminal that receives the first-stage signal at the potential of the IN (+) terminal. This prevents noise and disturbances due to the inter-wire capacitance and stray capacitance from other wires from jumping into the input terminals and leakage current from potential generation.

As for the guard ring, in order to prevent noise from flying out as a loop antenna, a cut may be inserted halfway, but the presence or absence of the cut should be judged by experiments on the actual board, etc. If no cuts are inserted, make the area surrounding it as small as possible to reduce the magnetic flux passing through the loop.

### 4. Product Overview

#### 4.1. TC75S67TU

- Low Equivalent Output Noise Voltage:  
 $V_{NI}=16 \text{ nV}/\sqrt{\text{Hz}}$  (typ.) @ $f=10 \text{ Hz}$ ,  $R_S=100 \Omega$ ,  $R_F=10 \text{ k}\Omega$ ,  $V_{DD}=2.5 \text{ V}$ ,  $V_{SS}=\text{GND}$ ,  $G_V=40 \text{ dB}$   
 $V_{NI}=6 \text{ nV}/\sqrt{\text{Hz}}$  (typ.) @ $f=1 \text{ kHz}$ ,  $R_S=100 \Omega$ ,  $R_F=10 \text{ k}\Omega$ ,  $V_{DD}=2.5 \text{ V}$ ,  $V_{SS}=\text{GND}$ ,  $G_V=40 \text{ dB}$
- Low-input-bias current:  $I_I = 1 \text{ pA}$  (typ.)
- Low supply current:  $I_{DD} = 430 \mu\text{A}$  (typ.) @ $V_{DD}=2.5 \text{ V}$ ,  $V_{SS} = \text{GND}$
- Low power supply voltage drive:  $V_{DD}$ ,  $V_{SS}=2.2 \text{ to } 5.5 \text{ V}$

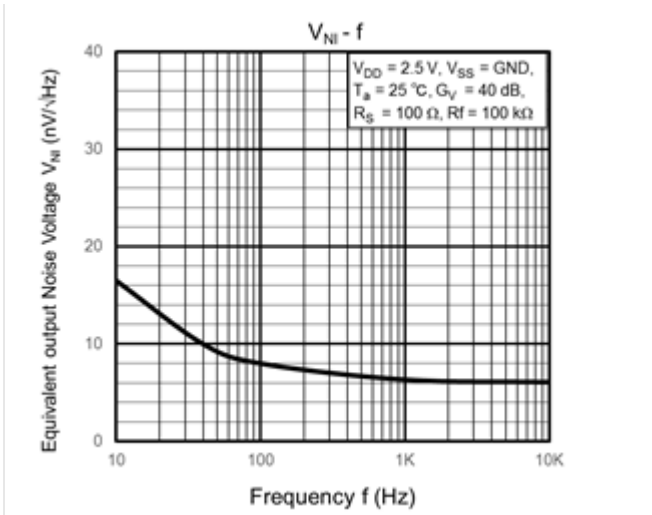


Fig.4.1 Equivalent Output Noise

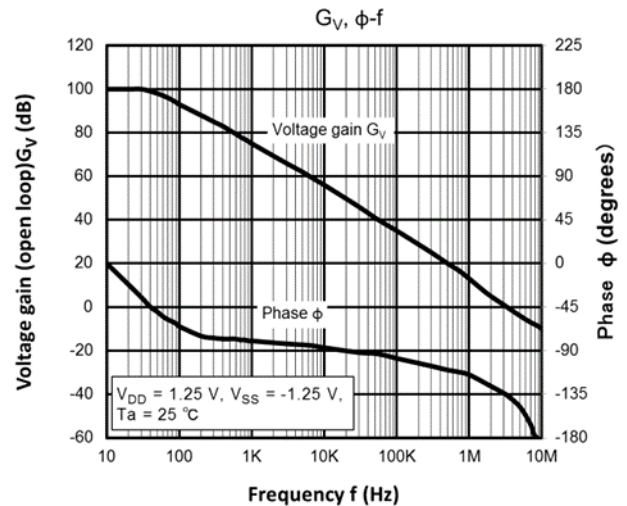


Fig.4.2 Phase Margin & Gain

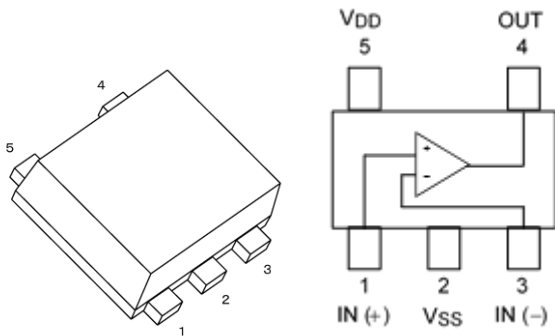


Fig.4.3 External View and Pin Assignment

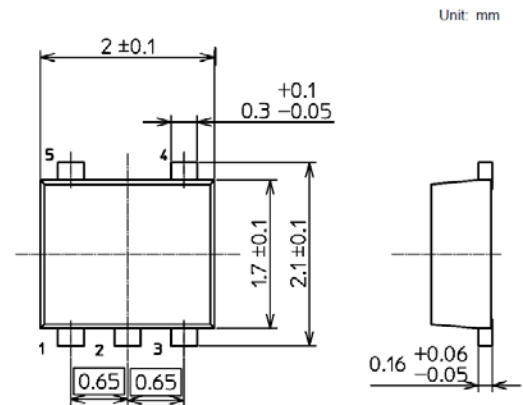


Fig.4.4 Dimensions

Refer to the data sheet for details of each characteristic.

To download the datasheet for TC75S67TU →

[Click Here](#)

## 4.2. Pin Description

**Table4.1 TC75S67TU Pin Descriptions**

Pin number	Pin name	Function
1	IN (+)	Non-inverting input pin
2	V <sub>SS</sub>	Connect this pin to GND when using a single power supply with a negative power supply terminal.
3	IN (-)	Inverting input terminal
4	OUT	Output terminal
5	V <sub>DD</sub>	The maximum rating for use with a single power supply with a positive power supply terminal is 6 V. For stable operation, it is recommended to use a bypass capacitor of 0.1 $\mu$ F and a capacitor of 0.01 $\mu$ F or more (ESR=1 $\Omega$ or less).

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