Example of low current consumption Operational Amplifiers (Op Amps) to dust sensor

Overview

Sensors are required to have low power consumption,especially on IoT equipment, etc. This document describes the designing of dust sensors using the low current consumption operational amplifiers TC75S102F, TC75S103F. It is useful for designing sensors for use in familiar home appliances such as air conditioners and air purifiers.

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1. Introduction

The dust sensors described are used in air cleaners, air conditioners, ventilators, vacuum cleaners, environmental monitors, etc. Dust generally affects human health such as allergy, and it affects the quality of products in factories. The dust sensor detects soil particles in the room such as PM2 5, pollen and cigarette smoke, bedding and dust by cleaning, and particles suspended in the air. In industrial applications, it is also used to detect dust in clean rooms such as factories that produce semiconductors and food factories.

This section describes the design of a dust sensor that optically detects dust using Infrared emitting diode (IR LED) and photodetectors.

For detailed information on the low quiescent current and low power op amps TC75S102F and TC75S103F used in this application note, refer to the data sheet of the link.

To download the datasheet for TC75S102F → Click Here

To download the datasheet for TC75S103F → Click Here

2. Dust Sensor Specifications

2.1. Dust Sensor Specifications

Table 2.1 shows the specifications of the dust sensor.

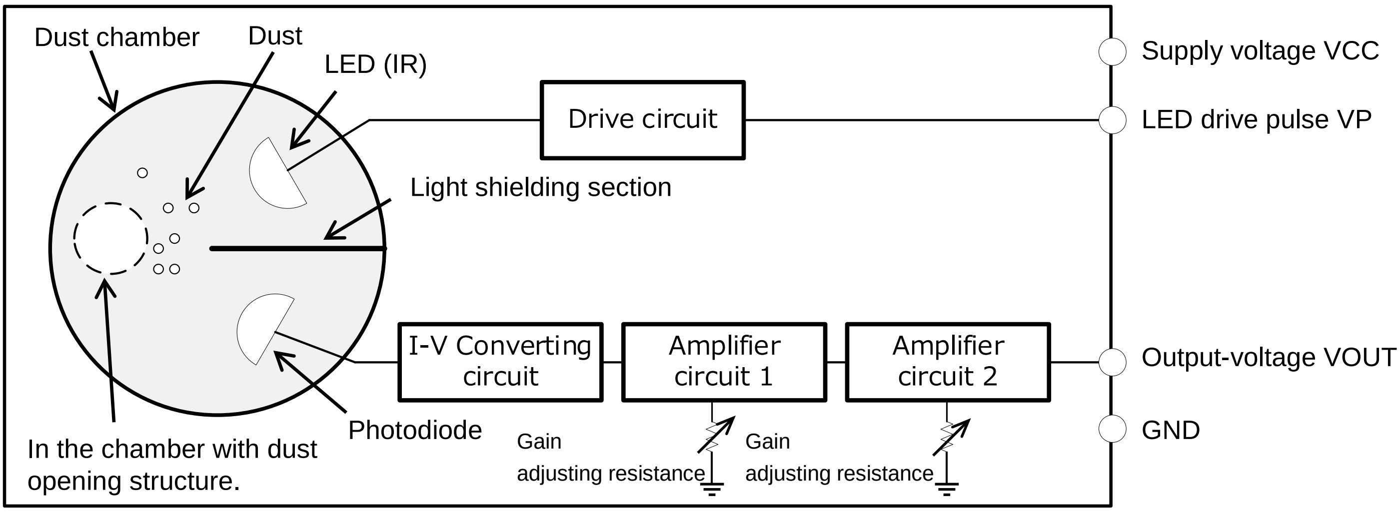
Table 2.1 Dust sensor specifications

Item	Specifications
Power supply voltage	3.3V
Current consumption	Approx. 300μA (Typ. @LED drive Duty5%)
Dust sensor	Scattered-light detector by IR LED and Photodiode
LED emission wavelength	900nm
Operational Amplifier	Toshiba Device & Storage TC75S102F and TC75103F

2.2. Dust sensor

Figure 2.1 shows the block diagram of the dust sensor.

Figure 2.1 Dust Sensor Block Diagram



The dust sensor described uses scattered light to detect dust. The dust sensor consists of an LED, photodiode, LED drive circuit, I-V (current-voltage) conversion circuit, and two amplifier circuits. In addition, the dust chamber for collecting dust with an opening structure for dust to enter.

To prevent infrared light emitted from the LED (IR) from entering the photodiode directly, a light shielding section is provided between the LED and the photodiode. When dust enters the chamber, the infrared light emitted from the LED is scattered by the dust. The scattered light is detected by a photodiode. Since the sensing current of the photodiode due to the detection of infrared light is as small as a few micro amperes, it is converted into a voltage by the I-V converting circuit, and this voltage is amplified and output by the two amplifier circuit.

3. Circuit design

This section describes the dust sensor circuit.

3.1. Dust Sensor LED Drive Circuit

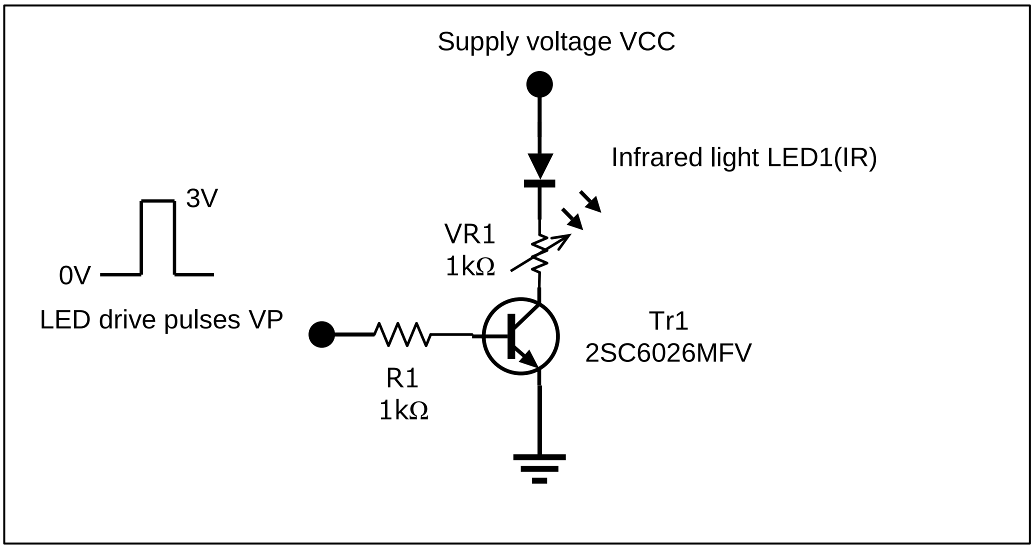
Figure 3.1 shows the LED drive circuit of the dust sensor. LED1 is an infrared light-LED.
The current I_{LED1} that flows through LED1 can be calculated from the following equation.

$$VCC = VF(LED) + Vce(sat) \times I_{LED1} + R1 \times I_{LED1} \quad \cdot\cdot\cdot\cdot \quad (1)$$

VCC shows the supply voltage and VF(LED) show the voltage in the forward direction of the LED, and Vce(sat) shows the saturated voltage of Tr1.

When VCC=3.3V, VF(LED)≒1.3V, Vce(sat)≒0. 2V, and R1=1kΩ, I_{LED1} is ≒2mA.

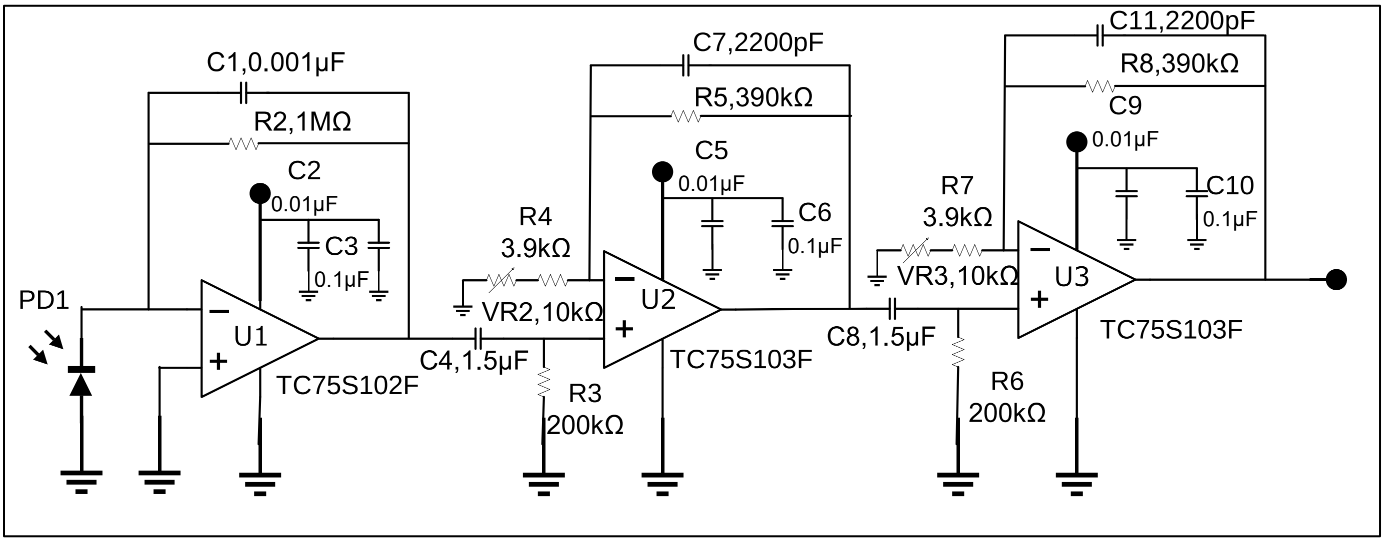
Fig.3.1 Dust Sensor LED Drive Circuit



3.2. Dust Sensor Signal Detection and Amplification Circuit

Figure 3.2 shows the signal detection and amplification circuit for the dust sensor.

Fig.3.2 Signal Detection and Amplification Circuit of dust sensor



The first stage circuit converts the output current of the photodiode PD1 to I-V (current-voltage). The output current of the photodiode is converted to voltage by op amps U1 and R2. R2 and C1 constitute a low pass filter to prevent oscillation of the operational amplifier.

The following equation calculates the cutoff frequency fc1 of the low pass filter (LPF) in the first stage.

$$fc1 = \frac{1}{(2 \times \pi \times R2 \times C1)} = \frac{1}{(2 \times \pi \times 1M \times 0.001\mu)} \cong 160Hz \cdot\cdot\cdot\cdot \ (2)$$

R2:1MΩ、C1:0.001 μF

The output voltage VOUT2 from the first stage circuit can be shown below, the electromotive current of the photodiode is IL.

$$VOUT2 = IL \times R2 \cdot\cdot\cdot\cdot \ (3)$$

C4 and R3 constitute a high pass filter (HPF). This circuit is used to eliminate noise in the low frequency region from the I-V conversion circuit in the first stage circuit. For the cutoff frequency fc2 of HPFs,

$$fc2 = \frac{1}{(2 \times \pi \times R3 \times C4)} = \frac{1}{(2 \times \pi \times 200k \times 1.5\mu)} \cong 0.53Hz \cdot\cdot\cdot\cdot \ (4)$$

R3:200kΩ、C4:1.5 μF

The second stage amplifier circuit also amplifies the signal of the photodiode converted to a voltage. R4, VR2 and R5 determine the gain of this amplifier. VR2 adjusts the gain GV1 of the amplifier. This circuit also has an LPF composed of R5 and C7 to eliminate unnecessary frequency signals and prevent oscillation of the operational amplifier circuit. The gain GV1 and the cutoff frequency fc3 of the LPF are as follows:

$$GV1 = \left[1 + \left\{\frac{R5}{(R4 + VR2)}\right\}\right] = 1 + \frac{390k}{3.9k} \cong 101 times \cdot \cdot \cdot \cdot \ (5)$$

R5: 390kΩ, R4:3.9kΩ, VR2:10kΩ (calculated as 0Ω in the above equation)

$$fc3 = \frac{1}{(2 \times \pi \times R5 \times C7)} = \frac{1}{(2 \times \pi \times 390k \times 2200p)} \cong 185Hz \cdot \cdot \cdot \cdot \ (6)$$

The third stage amplification circuit further amplifies the signal of the photodiode amplified by the second stage amplification circuit. The circuit configuration is the same as that of the second stage amplifier circuit. The HPF is composed of C8 and R6. For the cutoff frequency fc4 of HPF.

$$fc4 = \frac{1}{(2 \times \pi \times R6 \times C8)} = \frac{1}{(2 \times \pi \times 200k \times 1.5\mu)} \cong 0.53Hz \cdot \cdot \cdot \cdot \ (7)$$

R6:200kΩ、C8:1.5 µF

R7 and VR3 and R8 determine the gain GV2 of the amplifier. C11 and R8 also constitute LPFs with cut-off frequency fc5.

$$GV2 = \left[1 + \left\{\frac{R8}{(R7 + VR3)}\right\}\right] = 1 + \frac{390k}{3.9k} \cong 101 times \cdot \cdot \cdot \cdot \ (8)$$

R8: 390 kΩ, R7:3.9kΩ, VR3:10kΩ (calculated as 0 Ω in the above equation)

$$fc5 = \frac{1}{(2 \times \pi \times R8 \times C11)} = \frac{1}{(2 \times \pi \times 390k \times 2200p)} \cong 185Hz \cdot \cdot \cdot \cdot \ (6)$$

Therefore, the output voltage of the first stage is 101×101≈10,200 times as large as that of the second stage (GV=101 times) and the third stage (101 times).

For each op amps, 0.01µF/0.1µF is connected in parallel to the power supply pin as a bypass capacitor. Connect a capacitor with the smallest ESR possible to the power supply terminal of the op-amp as close as possible.

4. Operation result

The evaluation results of this dust sensor are described below.

4.1. Evaluation waveform

Indicates the input/output waveform of the dust sensor. In the absence of dust, the photodiode does not detect light because the infrared light from the LEDs in the dust chamber does not scatter, so the output-voltage from the dust sensor is 0V (Fig.4.1).

When there is dust, the light from the LED is scattered by the dust and the photodiode detects the light. For this reason, a voltage corresponding to the dust is output from the dust sensor at the same timing as the drive pulse that causes the LED to light(Fig.4.2).

Fig.4.1 Input / output waveform of dust sensor (There is no dust)

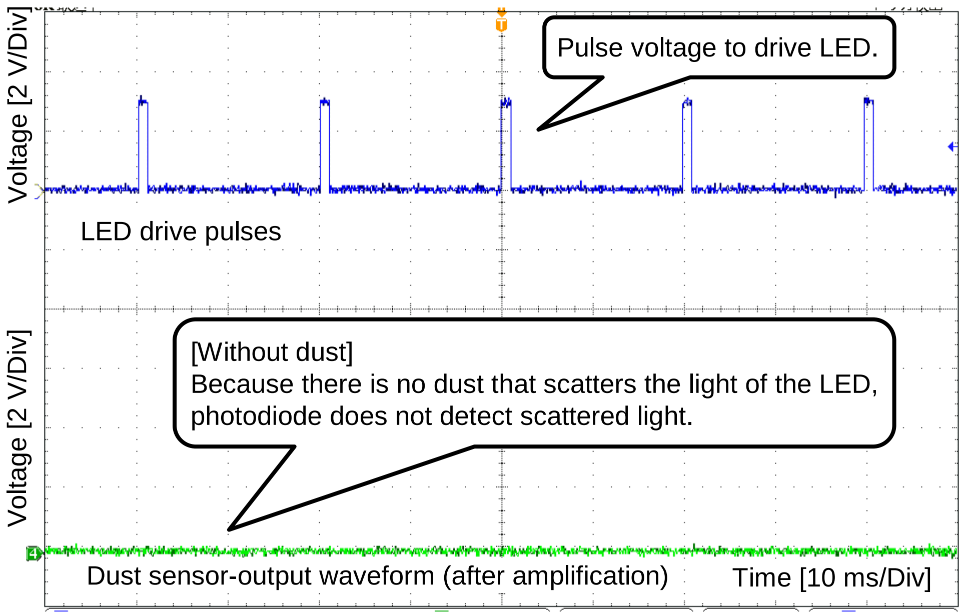
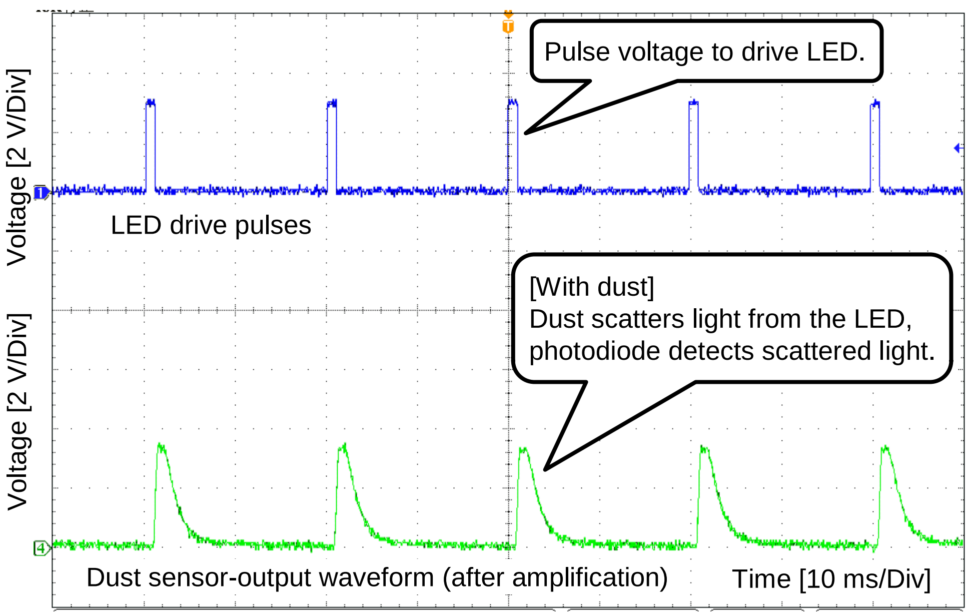


Fig.4.2 Input / output waveform of dust sensor (There is dust)



5. Bill of materials

5.1. Bill of Materials

Table 5.1 Bill of Materials

Item	Parts	Quantity	Value	Part name	Manufacturer	Description
1	U1	1	-	TC75S102F	TOSHIBA	Operational amplifier
2	U2, U3	2	-	TC75S103F	TOSHIBA	Operational amplifier
3	LED1	1	-	-	-	IR LED
4	PD1	1	-	-	-	Photodiode
5	Tr1	1	-	2SC6026MFV	TOSHIBA	Transistor
6	R1	1	1kΩ	-	-	1/4W, ±1%
7	C1	1	0.001μF	-	-	Ceramic Capacitor, 6.3V, ±10%
8	C2,C5,C9	3	0.01μF	-	-	Ceramic Capacitor, 6.3V, ±10%
9	C3,C6,C10	3	0.1μF	-	-	Ceramic Capacitor, 6.3V, ±10%
10	VR1	1	1kΩ	-	-	Potentiometer, 100 mW
11	VR2,VR3	2	10kΩ	-	-	Potentiometer, 100 mW
12	R3,R6	2	200kΩ	-	-	1/4W, ±1%
13	R4,R7	2	3.9kΩ	-	-	1/4W, ±1%
14	R5,R8	2	390kΩ	-	-	1/4W, ±1%
15	C4,C8	2	1.5μF	-	-	Ceramic, 6.3V, ±10%

6. Related Links

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