# Smart Analog IC 300

## Selecting Amplifiers Based on Sensor Type

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## Introduction

This application note explains how to select the configuration of the configurable amplifiers in Smart Analog IC 300 according to the sensor output circuit and its characteristics, and provides a description of each amplifier configuration.

## Target Device

Smart Analog IC 300 (RAA730300)

## Contents

# 1. Overview

## 1.1 General

Smart Analog is a group of products whose circuits and characteristics can be reconfigured by using software to enable support of many different types of sensors and drivers.

Smart Analog IC 300, which is a member of the Smart Analog group, provides three configurable amplifier channels whose circuitry and characteristics can be reconfigured to allow a range of sensors to be connected. This reconfiguration work can be easily carried out on your computer GUI by using Smart Analog Easy Starter provided by Renesas.

It is important to note, however, that because there are so many different types of sensors in existence, a certain amount of knowledge of sensor technologies and experience is required to select the best amplifier configuration for each sensor. Taking a long time to consider which amplifier configuration should be used might impact the smooth development of your sensor system.

This application note explains how to select the configuration of the configurable amplifiers incorporated in Smart Analog IC 300 based on the specifications and characteristics of the sensor to be connected in your system.

Sensors output many different kinds of data, including current and voltage values, and changes in resistance and capacitance. Only current and voltage output signals can be connected to Smart Analog IC 300. Other types of output signals must be externally converted into voltage or current signals before being input to Smart Analog IC 300.

This application note also provides a flowchart to show how to select the best configurable amplifier configuration for each type of sensor. The flowchart provides six possible configurations. These configurations differ depending on the output signal type, and the output current and output resistance of the sensor.

## 1.2 Related Application Notes

Related application notes are shown below. Also refer to these documents when using this application note.

- Smart Analog Evaluating Sensors By Using Smart Analog Easy Starter Ver. 2.0 (R02AN0017E)

# 2. Procedure for Evaluating Sensors to Be Connected to Smart Analog ICs

## 2.1 Procedure from acquiring to evaluating the sensor

The procedure from when you decide on the sensor to use to when evaluation of the connection between the sensor and your Smart Analog IC is complete is described below.

(1) Check your system requirements (required specifications).
Example: Measurement range, use environment

(2) Obtain the sensor data sheet.
Confirm the required items in the sensor data sheet.
Example: Sensor output type, sensitivity, output resistance

(3) Determine the parameters of the analog circuit.
Example: Gain, bias voltage

(4) Determine the required amplifier configuration by referring to the flowchart shown in Figure 3-1.

(5) Consider the connection between the sensor output pins and the Smart Analog IC input pins, and connect the sensor to the evaluation board.

(6) Design the configurable amplifier configuration and required analog parameters by using the GUI software Smart Analog Easy Starter and evaluate the sensor.

Figure 2-1 shows the sensor evaluation flowchart.

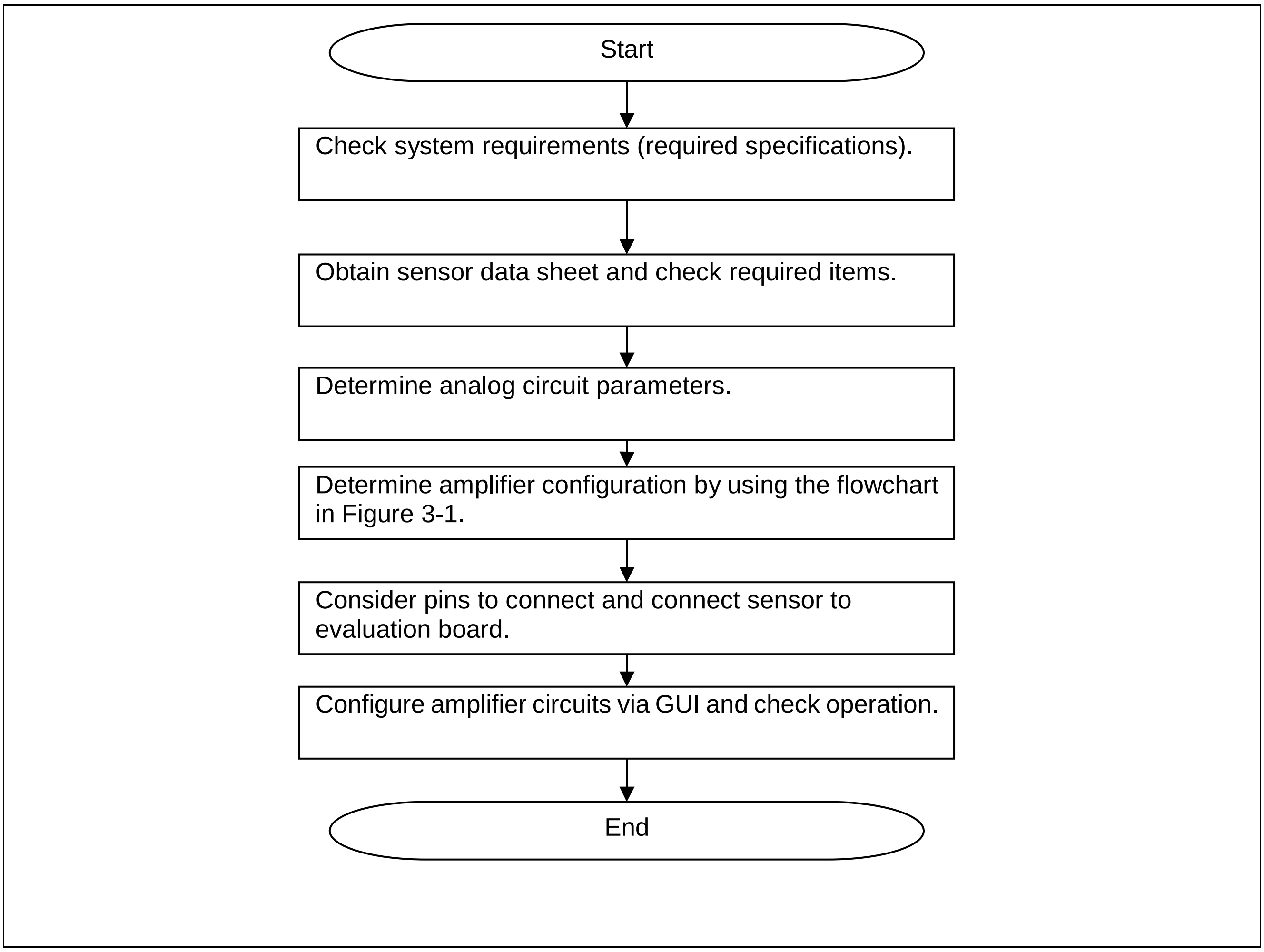



Figure 2-1 Sensor Evaluation Flowchart

## 2.2 Types of Sensors That Can Be Connected to Smart Analog IC 300

The sensors shown in Table 2-1 can be connected to Smart Analog IC 300.

Sensors detect physical quantities such as luminance, force, magnetism, and temperature and output that data as electrical signals. Sensors output various types of signals, which can differ even among sensors that detect the same physical quantities due to the sensing mechanism and sensor configuration.

Table 2-1 Examples of Physical Quantities Detected by Sensors and Sensor Output Types

| Physical Quantity (Detection Target) | Sensor | Output Signal Type | Example Application |
|---|---|---|---|
| Light | Motion sensor | Voltage | Security equipment |
| | Photodiode, UV sensor, infrared sensor, color sensor | Current | Smoke detectors, street lights, backlight control |
| | CdS cell | Resistance change | |
| Sound | Ultrasound sensor | Voltage | Distance measurement, sound detectors |
| | Microphone | Current | |
| Temperature | Thermocouple, semiconductor temperature sensor | Voltage | Thermometers |
| | Thermistor | Resistance change | |
| | Temperature transducer | Current | |
| Humidity, gas, odor | Gas sensor, odor sensor | Voltage | Alcohol detectors, gas leak detectors, hygrometers |
| | Humidity sensor | Resistance change, capacitance change | |
| Force | Load cell | Voltage | Scales, weight scales, barometers |
| | Air pressure sensor | Voltage (Differential outputs) | |
| Magnetism, current | Hall element | Voltage (Differential outputs) | Motors, voltmeters |
| | MR sensor | Voltage | |
| | Current transformer (CT) | Current | |
| Angular velocity | Gyro sensor | Voltage | Robots, cameras, attitude control |

Sensors that output voltage signals and current signals can be connected to Smart Analog IC 300. For sensors with other types of output signals, the signals must be externally converted into voltage or current signals before being input to Smart Analog IC 300. An example of how to convert the output of a piezoresistive sensor into a voltage output signal is shown below. A resistor is externally attached to the piezoresistive sensor as shown in Figure 2-2, configuring a resistor divider.

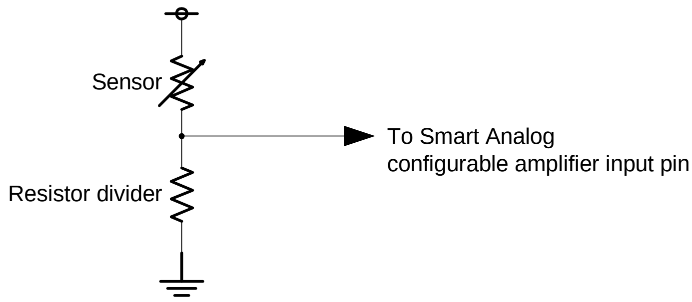



Figure 2-2 Example of Converting Piezoresistive Sensor

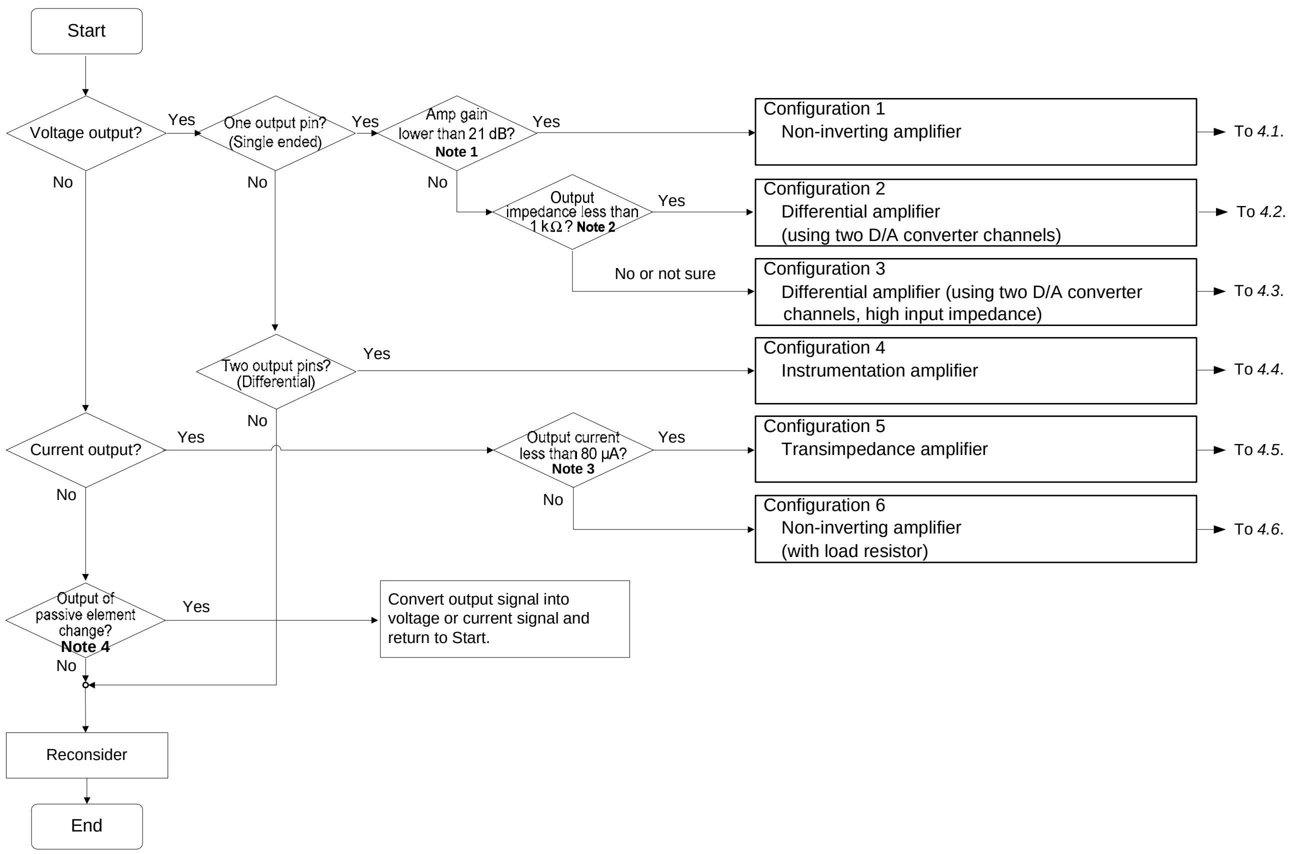
In order to determine the configuration of the configurable amplifiers in Smart Analog IC 300, it is necessary to identify the type of signal output by the sensor. If this information is not included in the sensor's data sheet, determine the output type by referring to Table 2-1. If the type of signal output by the sensor is not a voltage or current signal, convert the signal into a voltage or current signal by using an external component.

## 3. Flowchart for Selecting the Configurable Amplifier Configuration

The flowchart for selecting the configurable amplifier configuration is shown in Figure 3-1 below. This flowchart is provided for illustrative purposes to show how to select the amplifier configuration based on the specifications and characteristics of the sensor used. Note that the ideal configuration of the configurable amplifiers in Smart Analog IC 300 will differ depending on factors such as the output range, accuracy (current value, etc.), and equivalent circuits of the sensor, even for sensors that output the same type of signal (i.e., current output).

The following sensor data must be known to use this flowchart. Aspects of the flowchart such as the decision points might differ depending on your system specifications. Care is therefore required when using this flowchart to select an amplifier configuration.

- Sensor output signal type (current output or voltage output)
- Number of signals output by the sensor (Does the sensor have one output pin or two?)
- Gain required to amplify the signal output by the sensor (Higher or lower than 21 dB?)
- Output impedance of the sensor (Higher or lower than 1 kΩ?)
- Output current of the sensor (Higher or lower than 80 μA?)




Notes 1. The interval for DAC adjustment due to amplifier gain must not increase more than 86 mV, which is 10 times (20 dB).
2. The amplifier gain error caused by the sensor's output impedance must be kept to within 6%.
3. Make sure that the sensor's output current is lower than 80 μA to allow for voltage drop from the feedback resistor.
4. Such as impedance change, capacitance change, or inductance change

Figure 3-1 Selecting a Configurable Amplifier

# 4. Examples of Typical Amplifier Configurations Using Smart Analog IC 300

Smart Analog IC 300 has three on-chip configurable amplifier channels. The configurable amplifiers can be used independently or in combination. When operating a single amplifier, five amplifier configurations can be realized: a non-inverting amplifier, an inverting amplifier, a differential amplifier, a transimpedance amplifier, and a general amplifier. When operating amplifiers in combination, configurations such as an instrumentation amplifier and a differential amplifier with high input impedance can be realized.

This section describes the features of each of the configurations shown in Figure 3-1.

## 4.1 Non-Inverting Amplifier

A non-inverting amplifier amplifies the signal connected to the non-inverted input pin without inverting the signal, using the value of the inverted input pin as a reference. Because a non-inverting amplifier can directly receive the input signal at its input pin, the input impedance is high. This makes a non-inverting amplifier ideal for amplifying sensor signals whose output includes a resistance value.

- Advantages
  - Because the input impedance is high, a non-inverting amplifier is ideal for connecting to sensors whose output signals include resistance values.
  - Can be configured by using a single configurable amplifier channel.
- Disadvantages
  - The amplifier also amplifies the reference voltage output from the D/A converter. Therefore the step of D/A converter increases in proportion to the gain value.
  - The D/A converter is connected to the inverted input pin of the configurable amplifier, so when adjusting the output voltage by using the D/A converter, the voltage can only be adjusted downward.

Figure 4-1 shows a circuit diagram of a non-inverting amplifier that is configured by using configurable amplifier Ch1 and D/A converter Ch5 in Smart Analog IC 300.

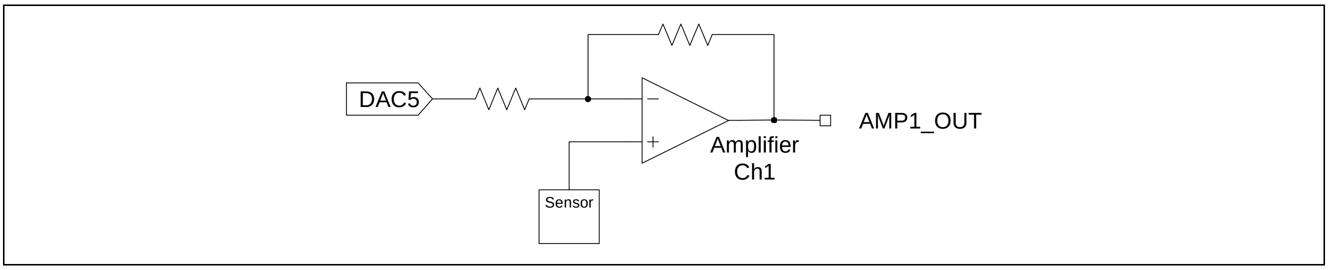



Figure 4-1 Non-Inverting Amplifier Circuit Diagram

## 4.2 Differential Amplifier (Using Two D/A Converter Channels)

A differential amplifier amplifies the difference between two input signals and outputs the result. Differential amplifiers are ideal for eliminating the offset voltage from sensors that include offset voltage. In this example, a single-ended output sensor is connected to the positive input of the differential amplifier and a D/A converter is connected to the negative input, and the amplifier is used as a non-inverting amplifier.

- Advantages
  — The output voltage can be easily adjusted even when the gain is high.
  — Can be configured by using a single configurable amplifier channel.
- Disadvantages
  — Because the input impedance is low, an error occurs in the gain when connecting to sensors whose output signals include resistance values.

Figure 4-2 shows a circuit diagram of a differential amplifier configuration implemented by using configurable amplifier Ch1 and D/A converter channels Ch1 and Ch5 in Smart Analog IC 300 being used as a non-inverting amplifier from the viewpoint of the sensor.

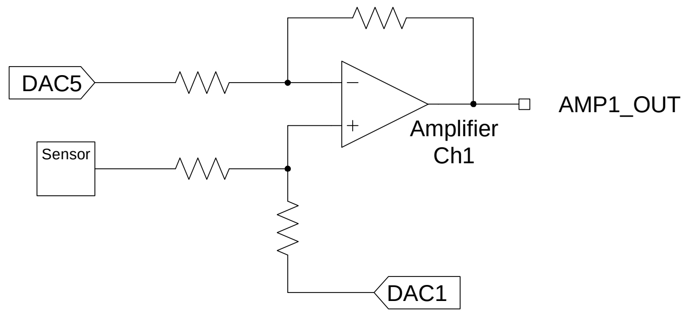



Figure 4-2 Circuit Diagram of Differential Amplifier (Using Two D/A Converter Channels)

## 4.3 Differential Amplifier (Using Two D/A Converter Channels and with High Impedance)

By using two configurable amplifier channels, a differential amplifier that combines the advantages of the non-inverting amplifier shown in Figure 4-1 and the differential amplifier shown in Figure 4-2 can be configured. A sensor is connected to one input of the differential amplifier and a D/A converter is connected to the other input, and the amplifier is used as a non-inverting amplifier.

- Advantages
  - Because the input impedance is high, this differential amplifier is ideal for connecting to sensors whose output signals include resistance values.
  - The output voltage can be easily adjusted even when the gain is high.
- Disadvantages
  - Two configurable amplifier channels are required.

Figure 4-3 shows a circuit diagram of a differential amplifier configuration implemented by using configurable amplifier channels Ch1 and Ch3 and D/A converter channels Ch3 and Ch7 in Smart Analog IC 300 being used as a non-inverting amplifier from the viewpoint of the sensor.

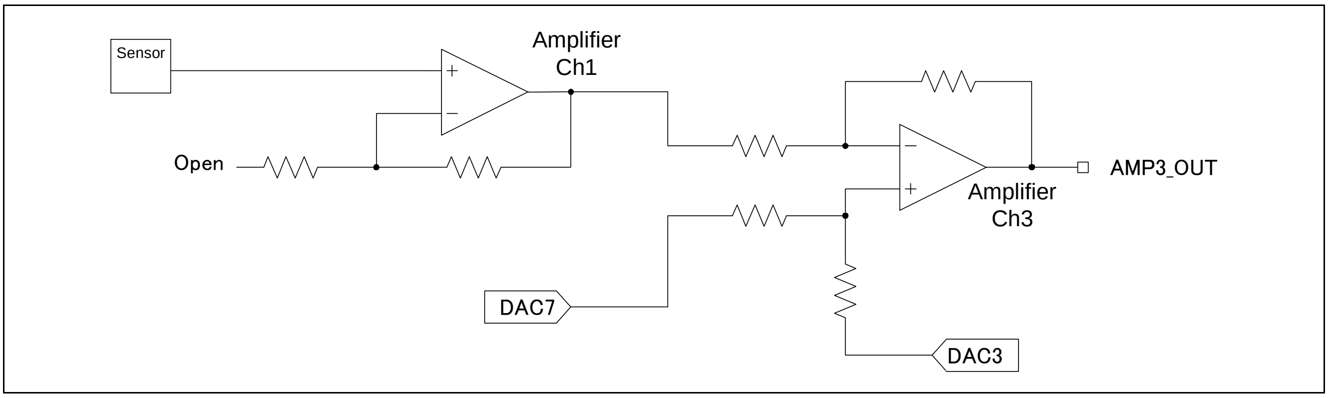



Figure 4-3 Circuit Diagram of Differential Amplifier (Using Two Configurable Amplifier Channels)

## 4.4 Instrumentation Amplifier

An instrumentation amplifier amplifies the difference between signals input to the amplifier in the same way as a differential amplifier, but like a non-inverting amplifier, it can also receive input signals directly at its input pin. This makes an instrumentation amplifier ideal for sensors whose output signals are differential outputs that include a resistance value, such as Wheatstone bridge sensors.

- Advantages
  - — Because the input impedance is high, an instrumentation amplifier is ideal for connecting to sensors whose output signals include resistance values.
  - — Can reject common-phase noise. (A high common mode rejection ratio (CMRR) can be obtained.)
- Disadvantages
  - — Three configurable amplifier channels are required.

Figure 4-4 shows a circuit diagram of an instrumentation amplifier that is configured by using configurable amplifier channels Ch1 to Ch3 and D/A converter Ch3 in Smart Analog IC 300.

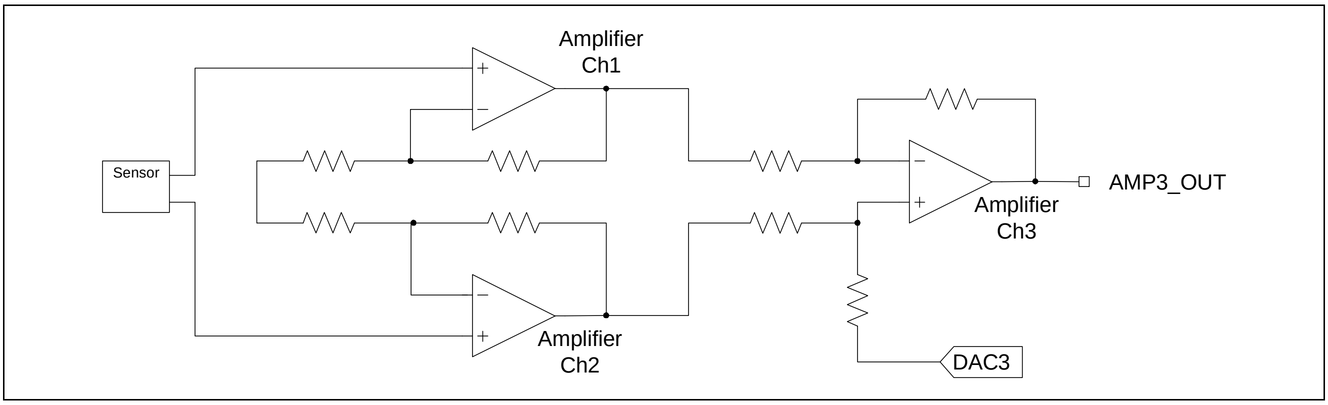



Figure 4-4 Instrumentation Amplifier Circuit Diagram

## 4.5 Transimpedance Amplifier

A transimpedance amplifier, also known as an impedance converting amplifier, converts a current input signal into a voltage value. This kind of amplifier is ideal for cases when you need to adjust the sensor's operating point for sensors that output current signals.

- Advantages
  — Can adjust the sensor's operating point.
- Disadvantages
  — If the sensor's output current is large, the voltage loss from the feedback resistor is also large.
  — Variation in feedback resistance leads to variation in gain.

Figure 4-5 shows a circuit diagram of a transimpedance amplifier that is configured by using configurable amplifier Ch1 and D/A converter Ch5 in Smart Analog IC 300.

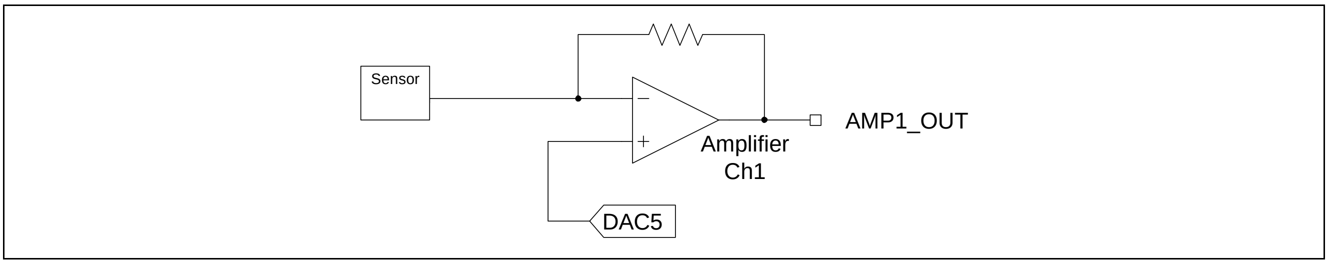



Figure 4-5 Transimpedance Amplifier Circuit Diagram

## 4.6 Non-Inverting Amplifier (with Load Resistor)

This amplifier is configured by externally connecting a resistor to the non-inverting amplifier shown in Figure 4-1. By using the external resistor as the sensor's load resistor, a current sensor can be used as a voltage sensor. This kind of amplifier is more effective than the transimpedance amplifier shown in Figure 4-5 for sensors that have a large output current, because the external resistance value can be selected.

- Advantages
  — Smaller gain error than the transimpedance amplifier shown in Figure 4-5.
- Disadvantages
  — An external resistor is required.
  — Current flows to the sensor even when the configurable amplifier is off.

Figure 4-6 shows a circuit diagram of a non-inverting amplifier that is configured by using configurable amplifier Ch1 and D/A converter Ch5 in Smart Analog IC 300.

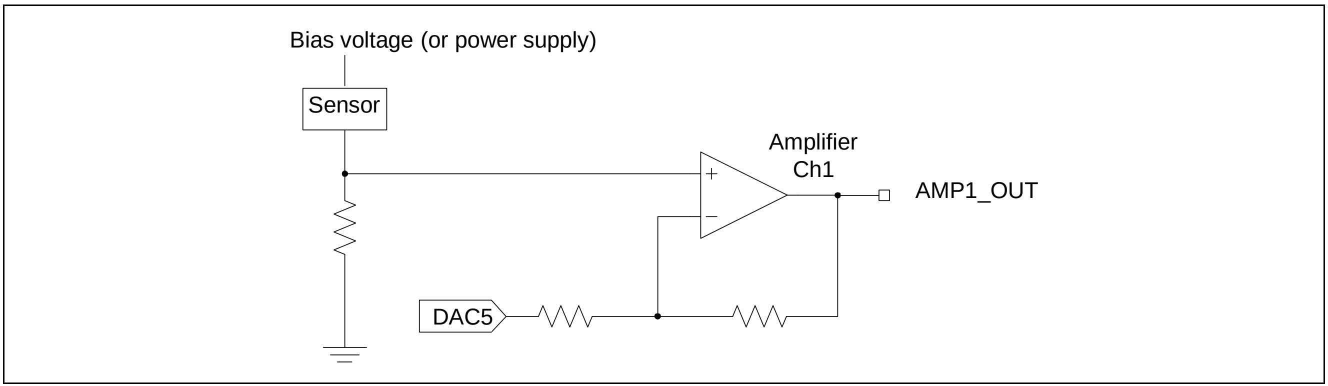



Figure 4-6 Circuit Diagram of Non-Inverting Amplifier (with Load Resistor)

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## Revision Record

| Rev. | Date | Description | |
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## General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this manual, refer to the relevant sections of the manual. If the descriptions under General Precautions in the Handling of MPU/MCU Products and in the body of the manual differ from each other, the description in the body of the manual takes precedence.

1. Handling of Unused Pins

   Handle unused pins in accord with the directions given under Handling of Unused Pins in the manual.

   — The input pins of CMOS products are generally in the high-impedance state. In operation with unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on

   The state of the product is undefined at the moment when power is supplied.

   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses

   Access to reserved addresses is prohibited.

   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals

   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.

5. Differences between Products

   Before changing from one product to another, i.e. to one with a different part number, confirm that the change will not lead to problems.

   — The characteristics of MPU/MCU in the same group but having different part numbers may differ because of the differences in internal memory capacity and layout pattern. When changing to products of different part numbers, implement a system-evaluation test for each of the products.

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