R02AN0008EJ0110
Rev.1.10
Sep. 30, 2013

Smart Analog IC 500

Selecting Amplifiers Based on Sensor Type

Introduction

This application note explains how to select the configuration of the configurable amplifiers in Smart Analog IC 500 according to the sensor output characteristics and provides a description of each configuration.

Operation Verified Devices

Smart Analog IC 500 (RAA730500)

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 500, 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 is made particularly easy by using Smart Analog Easy Starter provided by Renesas, which lets you change settings via your computer GUI.

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 500 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 directly connected to Smart Analog IC 500. Other types of output signals must be externally converted into voltage or current signals before being input to Smart Analog IC 500.

This application note also provides a flowchart to help you select the ideal amplifier configuration. 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.

- RL78/G1E Example of Measurement Using a Wheatstone Bridge Sensor (R01AN1045E)
- RL78/G1E Example of Measurement Using a Current Sensor (R01AN1055E)
- RL78/G1E Example of Measurement Using a Force Sensor (R01AN1056E)
- RL78/G1E Example of Measurement Using a Piezoelectric Sensor (R01AN1057E)
- Smart Analog Amplifier Selection - Example Implementation: Connection of Non-Inverting Amplifier (Configuration 1) and Gyro Sensor (R02AN0009E)
- Smart Analog Amplifier Selection - Example Implementation: Connection of Differential Amplifier (Configuration 2) and Motion Sensor (R02AN0010E)
- Smart Analog Amplifier Selection - Example Implementation: Connection of Differential Amplifier (Configuration 3) and MR Sensor (R02AN0011E)
- Smart Analog Amplifier Selection - Example Implementation: Connection of Instrumentation Amplifier (Configuration 4) and Hall Element (R02AN0012E)
- Smart Analog Amplifier Selection - Example Implementation: Connection of Transimpedance Amplifier (Configuration 5) and Photodiode (R02AN0013E)
- Smart Analog Amplifier Selection - Example Implementation: Connection of Non-Inverting Amplifier (Configuration 6) and Temperature Transduce (R02AN0014E)

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 you want 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 using 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.

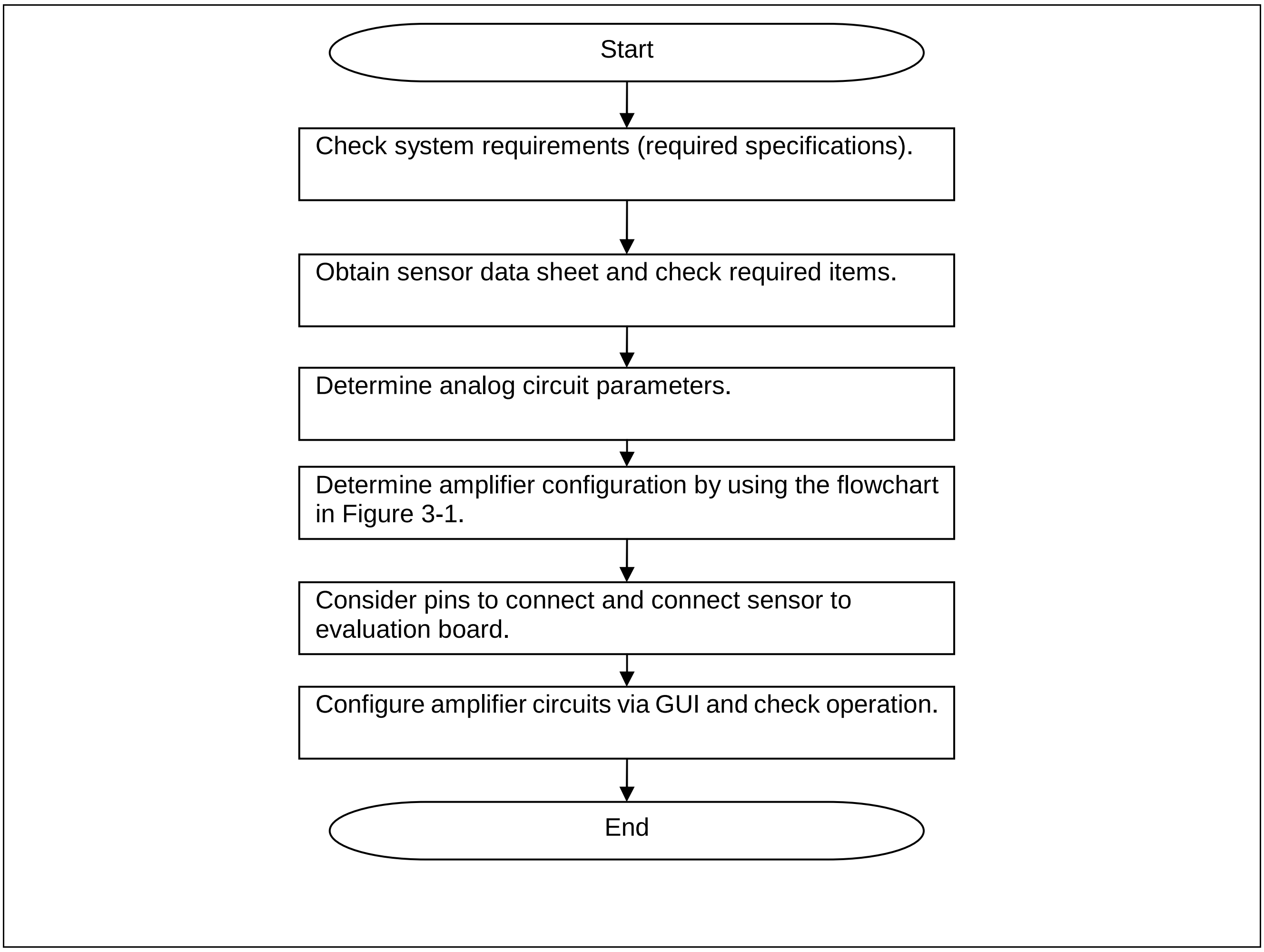


Figure 2-1 Sensor Evaluation Flowchart

2.2 Types of Sensors That Can Be Connected to Smart Analog IC 500

The sensors shown in Table 2-1 can be connected to Smart Analog IC 500.

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[Note 2]	Voltage	Security equipment
	Photodiode[Note 5], UV sensor, infrared sensor, color sensor	Current	Smoke detectors, street lights, backlight control
	CdS cell	Resistance change	
Sound	Ultrasound sensor	Voltage	Sound detectors, distance measurement
	Microphone	Current	
Temperature	Thermocouple, semiconductor temperature sensor	Voltage	Thermometers
	Thermistor	Resistance change	
	Temperature transducer	Current	
Humidity, gas, odor	Gas sensor, odor sensor	Voltage	Hygrometers, alcohol detectors, gas leak detectors
	Humidity sensor	Resistance change, capacitance change	
Force	Load cell	Voltage	Scales, weight scales, barometers
	Air pressure sensor	Voltage (differential)	
Magnetism, current	Hall element[Note 4]	Voltage (differential)	Motors, voltmeters
	MR sensor[Note 3]	Voltage	
	Current transformer (CT)[Note 6]	Current	
Angular velocity	Gyro sensor[Note 1]	Voltage	Robots, cameras, attitude control

Notes: For the detailed settings of the sensors described in this document, see the following application notes:

1. Amplifier Selection - Example Implementation: Connection of Non-Inverting Amplifier (Configuration 1) and Gyro Sensor
2. Amplifier Selection - Example Implementation: Connection of Differential Amplifier (Configuration 2) and Motion Sensor
3. Amplifier Selection - Example Implementation: Connection of Differential Amplifier (Configuration 3) and MR Sensor
4. Amplifier Selection - Example Implementation: Connection of Instrumentation Amplifier (Configuration 4) and Hall Element
5. Amplifier Selection - Example Implementation: Connection of Transimpedance Amplifier (Configuration 5) and Photodiode
6. Amplifier Selection - Example Implementation: Connection of Non-Inverting Amplifier (Configuration 6) and Current Transformer

Sensors that output voltage signals and current signals can be directly connected to Smart Analog IC 500. 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 500. 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.

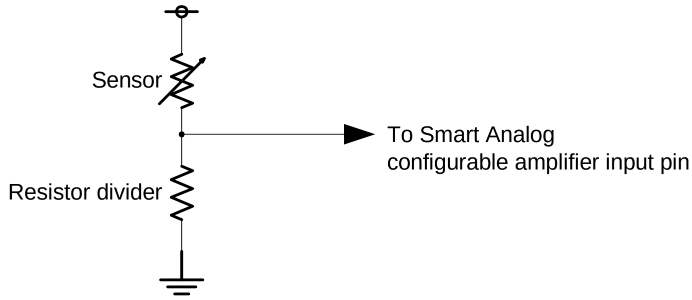


Figure 2-2 Example of Converting Piezoresistive Sensor

In order to determine the configuration of the configurable amplifiers in Smart Analog IC 500, 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.

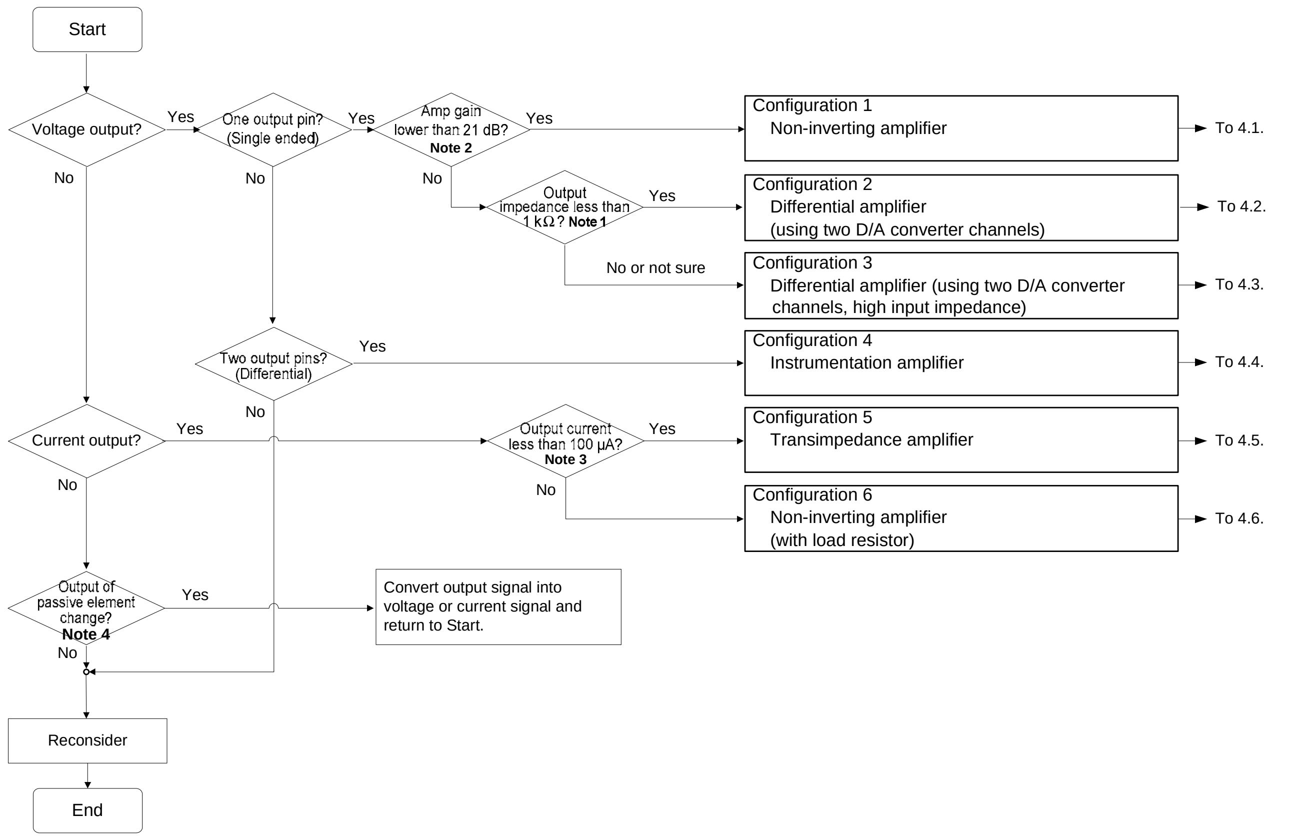
3. Flowchart for Selecting the Configurable Amplifier Configuration

The flowchart for selecting the configurable amplifier configuration is shown in Figure 3-1 below. This flowchart is one of the examples 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 500 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:

- Signal type of a sensor's output (current output or voltage output)
- Number of output signals from a sensor (Does the sensor have one output pin or two?)
- Gain which is required to amplify the output signal from a sensor (Higher or lower than 21 dB?)
- Output impedance of a sensor (Higher or lower than 1 kΩ?)
- Output current of a sensor (Higher or lower than 100 μA?)

It is needed, however, to change the value of branch condition depending on the requirement for the systems. Note that this flowchart is one of the examples to select the amplifier configuration.



Notes
1. The gain error of an amplifier caused by the output impedance must be kept to within 5%.
2. The widening of an adjustment step of DAC output voltage caused by the amplifier gain must be no more than 195 mV for a gain of x10 (20 dB).
3. Considering a large voltage loss which occurs from the feedback resistor of an amplifier, a sensor output current must be less than 100μA.
4. Such as impedance, capacitance, or inductance.

Figure 3-1 Selecting a Configurable Amplifier

4. Examples of Typical Amplifier Configurations Using Smart Analog IC 500

Smart Analog IC 500 has three on-chip configurable amplifier channels. The configurable amplifier channels can be used independently or in combination. When operating a single channel, four amplifier configurations can be realized: a non-inverting amplifier, an inverting amplifier, a differential amplifier, and a transimpedance amplifier. When operating channels 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 input to the non-inverted input pin based on the value of the inverted input pin but without inverting the signal. 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
  - If the gain is raised, the reference voltage output from the D/A converter also increases, so that an adjustment step of output voltage from D/A converter widens and cannot be fine enough for the requirement of some systems.
  - 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 output 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 Ch1 in Smart Analog IC 500.

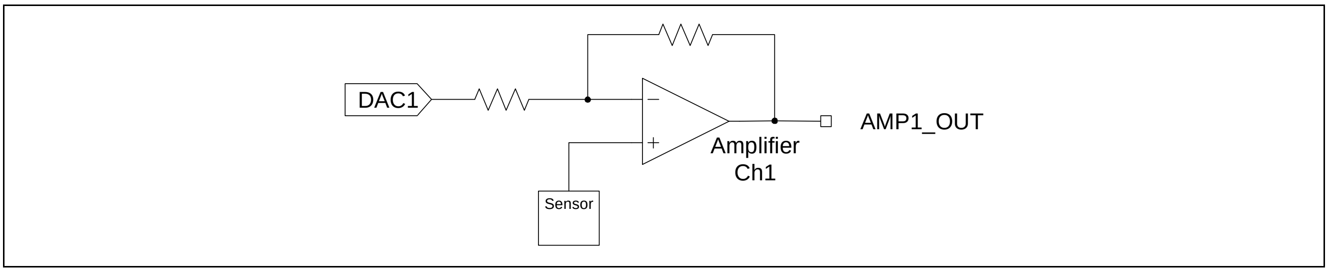


Figure 4-1 Non-Inverting Amplifier Circuit Diagram

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, an amplifier functions as a non-inverting amplifier in the configuration of a differential amplifier with the non-inverted input pin connected to the single-end output of a sensor and with the inverted input pin connected to the D/A converter.

- Advantages
  - Can realize the fine adjustment of the output voltage even when the gain is high.
  - Can be configured by using a single configurable amplifier channel.
- Disadvantages
  - Two D/A converter channels are required.
  - The input impedance is low so that the gain error occurs if the sensor's output impedance is relative high.

Figure 4-2 shows a circuit diagram of a differential amplifier that is configured by using configurable amplifier Ch1 and D/A converter channels Ch1 and Ch2 in Smart Analog IC 500. This circuit diagram below is also an example of a non-inverting amplifier for the connected sensor.

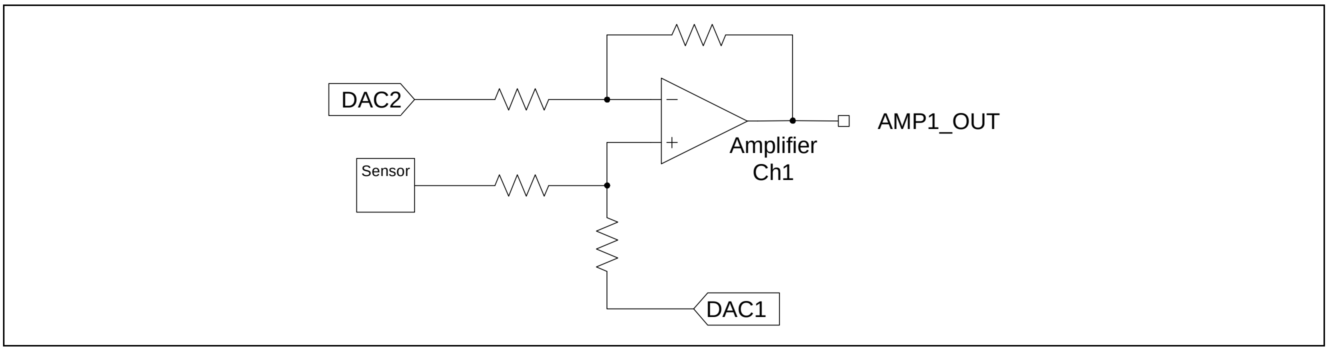


Figure 4-2 Circuit Diagram of Differential Amplifier (Using Two D/A Converter Channels)

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

By using three 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. In this example, an amplifier functions as a non-inverting amplifier in the configuration of a differential amplifier with one input pin connected to output of a sensor and with another input pin connected to the D/A converter. However, because it requires three configurable amplifier channels to configure this amplifier, only one sensor can be used at one time.

- Advantages
  - Because the input impedance is enough high, this differential amplifier is ideal for connecting to sensors whose output impedance are relative high.
  - Can realize the fine adjustment of the output voltage even when the gain is high.
- Disadvantages
  - Three configurable amplifier channels and two D/A converter channels are required.

Figure 4-3 shows a circuit diagram of a differential amplifier that is configured by using configurable amplifier channels Ch1 to Ch3 and D/A converter channels Ch1 and Ch2 in Smart Analog IC 500. This circuit diagram below is also an example of a non-inverting amplifier for the connected sensor.

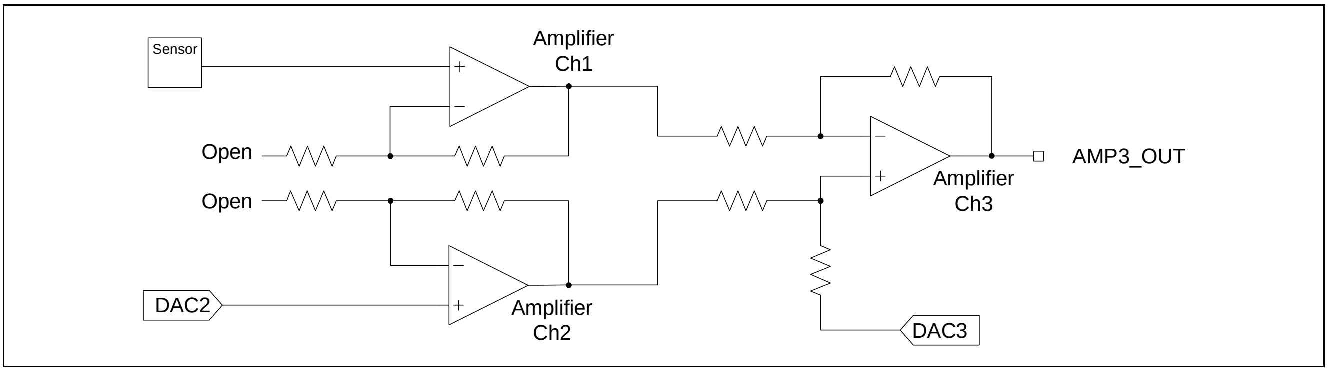


Figure 4-3 Circuit Diagram of Differential Amplifier (Using Three Configurable Amplifier Channels)

Figure 4-4 shows another example of the differential amplifier whose input impedance is enough high. Comparing the circuit diagram in Figure 4-4 with the one in Figure 4-3, you can see that configurable amplifier Ch2 is not being used. Configurable amplifier Ch2 can therefore be connected to the other sensor.

- Advantages
  - In the same way as in Figure 4-3, because the input impedance is high, this differential amplifier is ideal for connecting to sensors whose output signals include resistance values.
  - Unlike Figure 4-3, however, two sensors can be used at the same time.
- Disadvantages
  - The DAC1_OUT pin must be externally connected to the MPXIN60 or MPXIN61 pin.

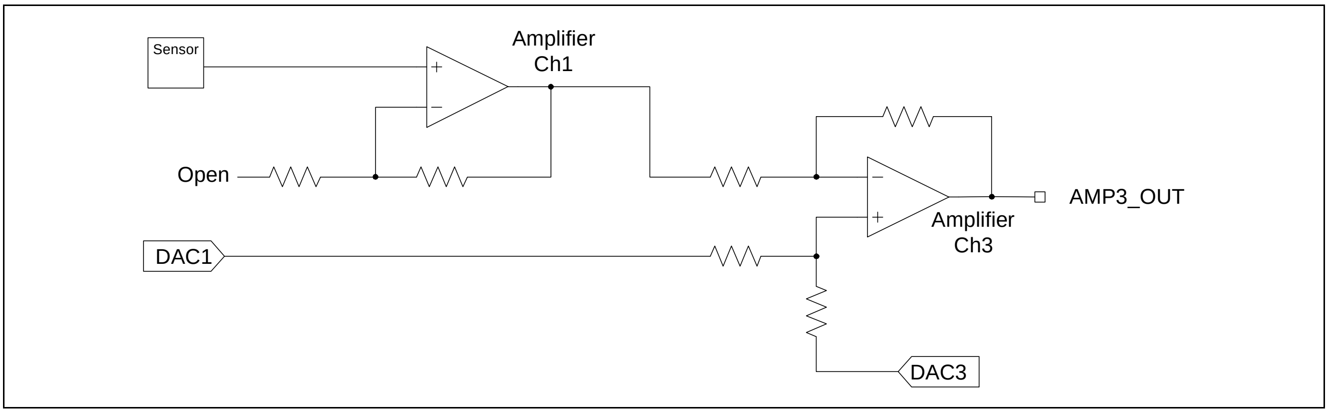


Figure 4-4 Circuit Diagram of Differential Amplifier (Using Two Configurable Amplifier Channels)

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 mode noise. (A high common mode rejection ratio (CMRR) can be obtained.)
- Disadvantages
  — Three configurable amplifier channels are required.

Figure 4-5 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 500.

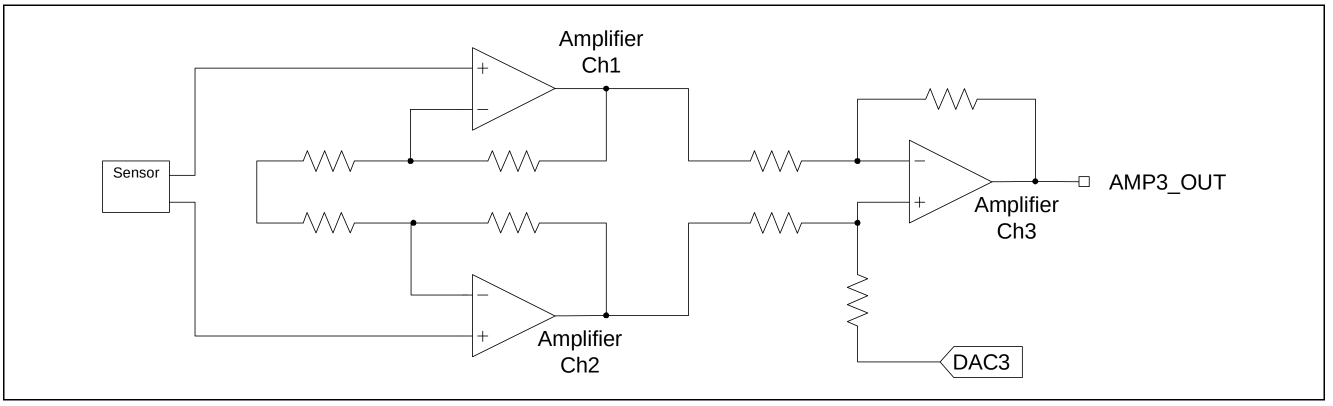


Figure 4-5 Instrumentation Amplifier Circuit Diagram

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 easily.
- 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 4-6 shows a circuit diagram of a transimpedance amplifier that is configured by using configurable amplifier Ch1 and D/A converter Ch1 in Smart Analog IC 500.

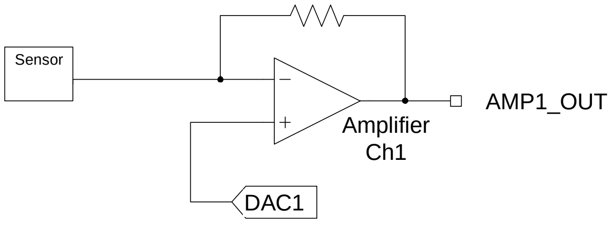


Figure 4-6 Transimpedance Amplifier Circuit Diagram

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. The circuit as a whole has a non-inverting amplifier configuration with high input impedance, and amplifies the voltage input to the non-inverted input pin. This kind of amplifier is available for sensors that have a large output current by selecting the resistance value of an external resister, compared with the transimpedance amplifier shown in Figure 4-6.

- Advantages
  — Smaller gain error than the transimpedance amplifier shown in Figure 4-6.
  — Can be configured by using a single configurable amplifier channel.
- Disadvantages
  — An external resistor is required.
  — Current flows to the sensor even when the configurable amplifier is off.

Figure 4-7 shows a circuit diagram of a non-inverting amplifier that is configured by using configurable amplifier Ch1 and D/A converter Ch1 in Smart Analog IC 500.

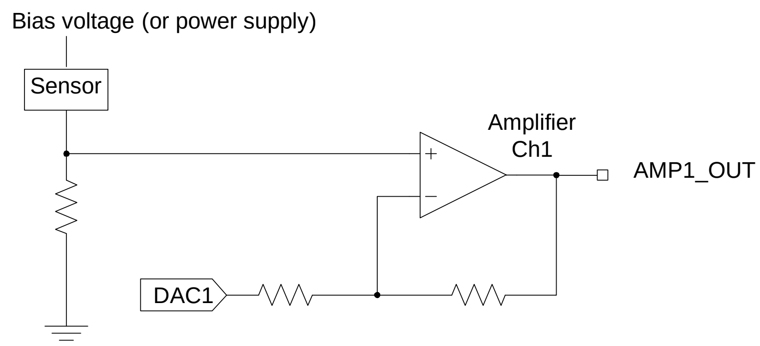


Figure 4-7 Circuit Diagram of Non-Inverting Amplifier (with Load Resistor)

Website and Support

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Revision Record

Rev.	Date	Description	
		Page	Summary
1.00	Sep. 30, 2012	–	First edition issued.
1.10	Sep. 30, 2013	6	Figure 3-1 is changed.
1.10	Sep. 30, 2013	—	The wrong words are removed to the correct words. Some explanations are added for more details. Some descriptions are changed to more appropriate one.

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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Colophon 2.2