

## White Paper

# The Benefits of Using RA2A1 MCUs in Measurement Systems

December 2020

## Abstract

Measurement systems in fields such as building automation, healthcare, and industry, are responsible for the important role of collecting data from sensors, ensuring the operational efficiency and reliability of equipment, and confirming the safe operation of equipment. This white paper explains how RA2A1 MCUs, equipped with an analog front-end circuit that can be flexibly configured for such measurement systems, are implemented, and how they contribute to reducing mounting components, making designing easier, and reducing time-to-market.



Sensors such as pressure, weight, temperature, distance, and biosensors are commonly used in applications such as medical devices, factory systems, and building automation. These sensors can be detected and measured using the characteristics of generating an electrical analog signal that correlates to the physical characteristics of the sensor. Most sensors output weak analog signals that are susceptible to noise. Therefore, in order to perform data acquisition with high accuracy, it is necessary to reliably capture and amplify weak signals and convert them into highly accurate digital signals. In addition, the design requires expertise and knowledge. On the other hand, designers are faced with the challenges of accurate system design, cost reduction, and strict delivery, and reducing the burden of complex designs is one of the key options for overcoming many design challenges.

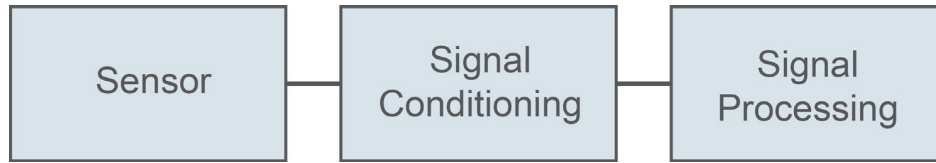
This white paper describes how the microcomputer with built-in high-precision analog circuits for measurement systems can reduce external components and reduce design complexity by taking advantage of its high degree of integration and flexibility. RA2A1 MCUs have a built-in high-function, high-resolution analogue function. By controlling analog switch blocks connected to multiple operational amplifiers within the MCU, by software and freely changing the connection path of the operational amplifiers, a variety of analog front-end circuits can be constructed from basic analog circuits to complex analog blocks with minimal external components.

## Configuration of the Measurement System

The basic configuration of the measurement system consists of three blocks: sensors, signal conditioning, and signal processing, as shown in Figure 1. The sensor block converts the physical characteristics (force, etc.) of the sensor into electrical signals (voltage, current, capacitance, etc.). The signal

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conditioning block adjusts the change of the weak signal to a voltage level suitable for processing the subsequent block. The signal processing block converts analog signals to digital signals. Analyzing this digital signal enables you to perform specific tasks on your system and perform operations.



**Figure 1:** Basic block configuration of the measurement system

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The signal conditioning block is a very important element that influences the superiority or inferiority of the measurement system. Sensor signals are very sensitive because they are generally weak. The weak signal output is susceptible to noise and requires careful handling during the adjustment stage of the sensor signal. Some types of noise are generated inside the MCU or have been induced or intruded from outside, which distorts the output signal of the sensor.

The electronic components used in the signal conditioning block should be carefully selected because their electrical characteristics can have a significant impact on the quality of the signal conditioning block. This white paper provides a brief description of the signal conditioning circuitry and describes the effects of the most important electrical characteristics among the electronic components commonly used in signal conditioning circuitry.

A signal processing block is a data converter that typically consists of an AD converter and a linearizing circuit. The accuracy and resolution specifications of the AD converter are particularly important because they can have a significant impact on the performance of the entire measurement system. The resolution is defined as the error between the actual value and the measured value. If this error is too large, the measurement system may lead to irregular operation or erroneous behavior of the entire system. This document describes the most common elements of signal processing and their electrical specifications.

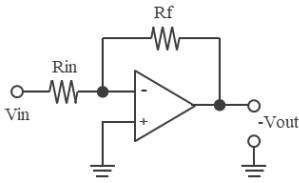
RA2A1 has a built-in high-performance analog function, which makes it possible to configure flexible and easy-to-use analog circuitry, so that the signal conditioning block and signal processing block can be realized in a single chip.

## Signal Conditioning

Generally, the signal output by the sensor is a weak signal, so it must be properly adjusted before performing digital processing. Figure 2 shows the most common signal conditioning circuits such as amplification, filtering, and impedance coupling.

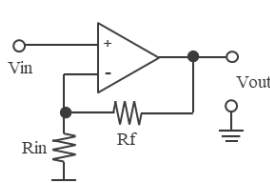
## Amplification

Inverting op-amp



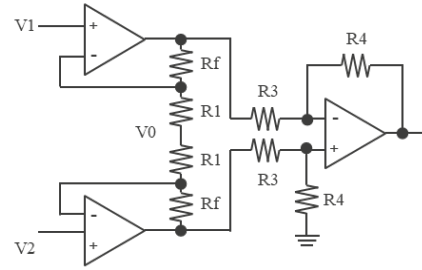
$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

Non-inverting op-amp



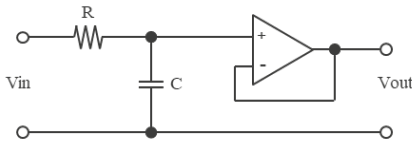
$$A = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_{in}}$$

Instrumentation amplifier



## Filters

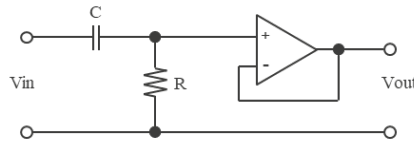
Low pass filter



$$f = \frac{1}{2\pi RC}$$

Non-inverting unity amplifier

High pass filter



$$f = \frac{1}{2\pi RC}$$

## Impedance Coupling

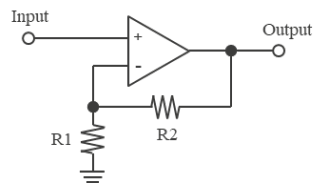
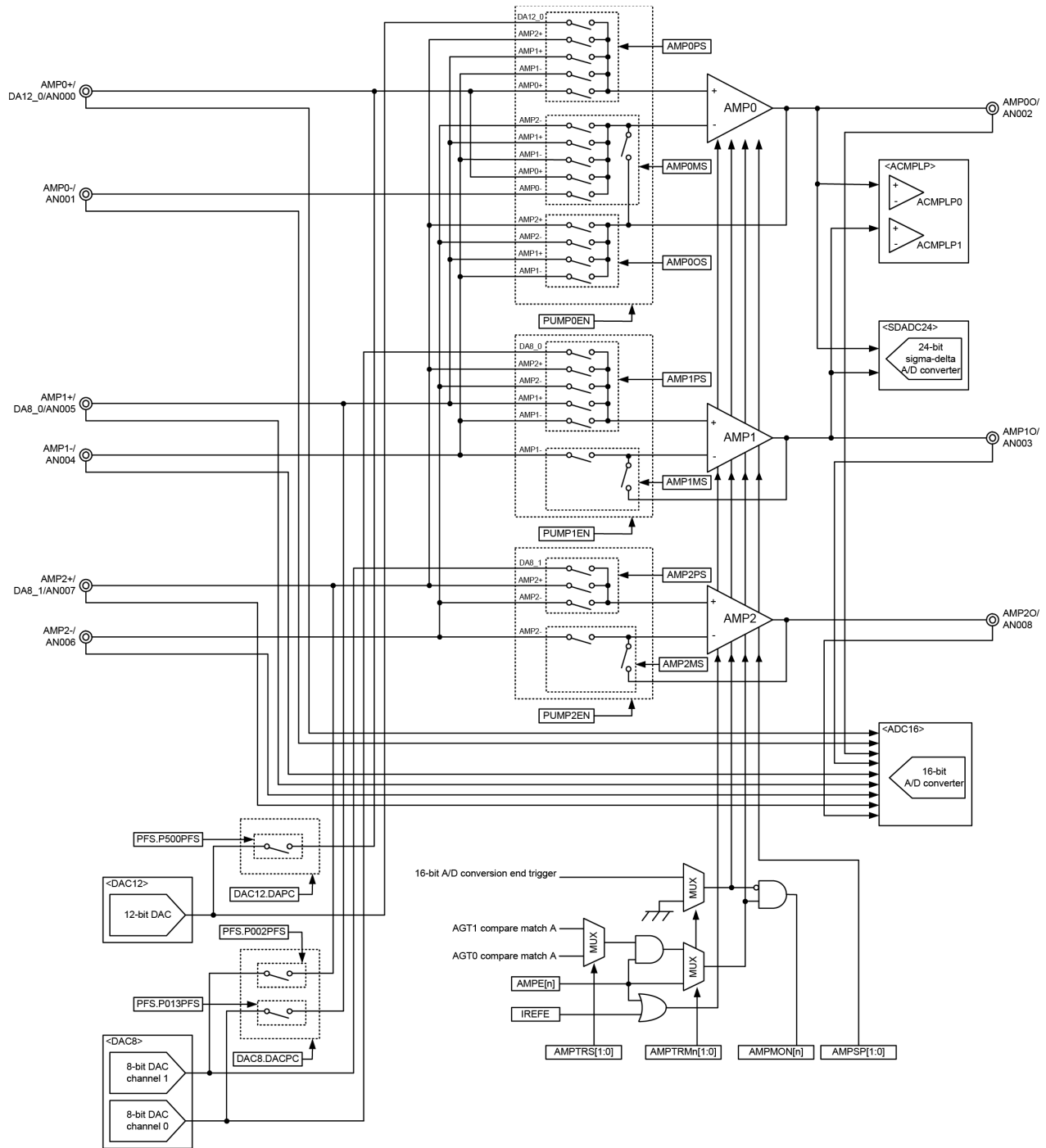


Figure 2: Typical signal conditioning circuit example

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Conventionally, it was very difficult to incorporate sensitive specifications such as input offset, rail-to-rail operation, and input noise density into microcontroller products. Therefore, the signal conditioning circuitry was implemented using external discrete components (OP-AMPS); however, advances in process and design technologies have made it possible to incorporate these circuits of extremely high quality and reliability.

RA2A1 MCUs have three built-in operational amplifiers. In addition, the input and output signals of each op-amp are connected to the analog switch block and their switch settings can be changed by software, which allows the user to easily configure various signal conditioning circuits with minimal external components. Figure 3 shows the configuration of each op-amp and analog switch block. It also provides a brief overview of the features.



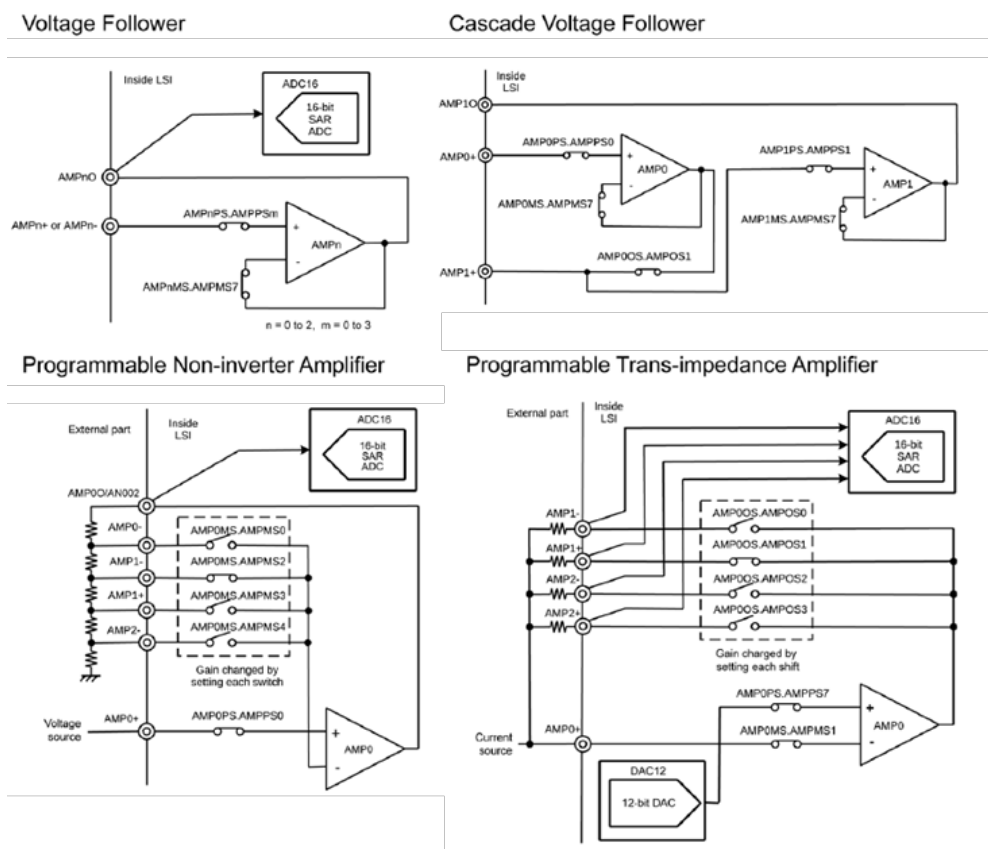
**Figure 3:** Signal-conditioning circuitry with RA2A1 op-amp3

RA2A1's built-in op-amp (AMP0~AMP2) has the following functions and modes of operation, allowing a wide variety of analog-front-end circuits to be constructed. In addition, internal connections combining analog switches eliminate the need for wiring for external MCU components and their connections, eliminating the need for complex wiring on printed circuit boards.

- Of the three-unit op-amps, AMP0 and AMP1 can be used as inputs for low-power analog comparators (ACMLP) and 24-bit sigma delta A/D converters (SDADC24).

- Operation mode can be selected from high-speed mode (large current consumption), medium-speed mode (medium current consumption), and low-power mode (low-speed response). Because of the trade-off between response speed and current consumption, the mode can be set to suit the operating environment.
- Operation can be started by triggering an asynchronous general-purpose timer (AGT).
- Operation can be stopped by the conversion end trigger of the 16-bit A/D converter.
- The input signal of all operational amplifiers can be selected by the switch. In addition, the output signal of the op-amp AMP0 can also be connected to the input of other op-amps.
- The output of the operational amplifier AMP0~AMP2 can be output from AMP00 pin to AMP20 pin without passing through the switch.
- The I/O pins of all operational amplifiers can be used as input signals for 16-bit A/D converters (ADC16).
- 8 signal outputs from 8-bit D/A converters (DAC8) and 12-bit D/A converters (DAC12) can be used as positive input signals for respective op-amps.
- A voltage follower circuit can be configured by feeding back the output signal of each op-amp as its own negative input signal.

Figure 4 shows a general signal conditioning circuit. These circuits can be easily configured by software-configuring the analog switch blocks inside the RA2A1 MCU.



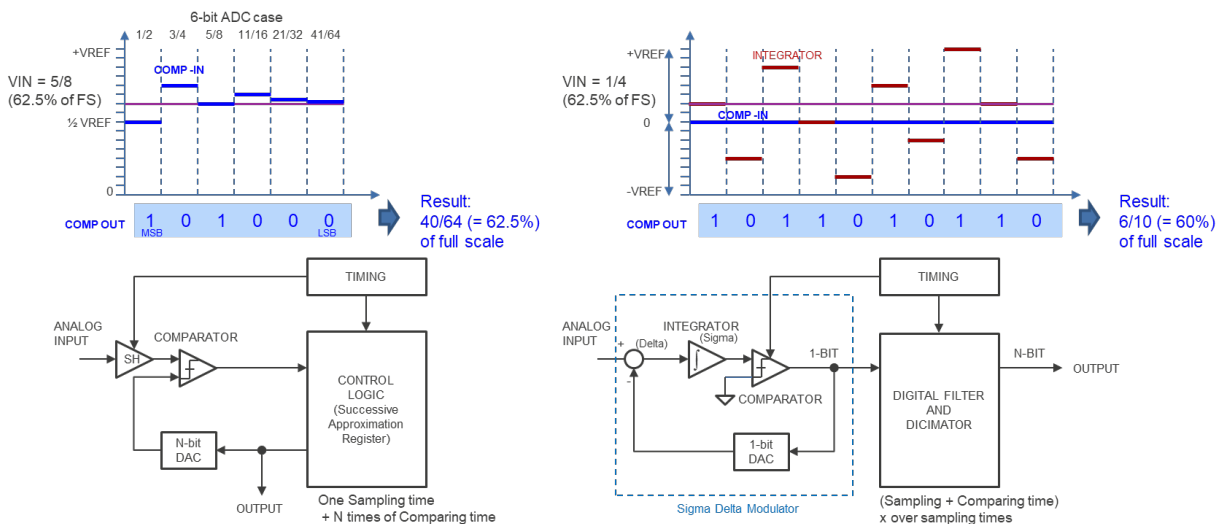
**Figure 4:** Implementation of a signal-conditioning circuitry using an RA2A1 op-amp

Other amp configurations, such as instrumentation amps and D-A buffer amps, can be easily implemented by changing the analog switch block settings. Since the analog switch block can be set and changed by software, some amplifier configurations can also be implemented while the MCU is running and can be applied to new applications. In addition to flexible configurable amp configurations, RA2A1 operational amps also provide user trimming capabilities that allow you to adjust offsets to your needs.

## Signal Processing

One of the basic functions of the signal processing block is the analog-to-digital converter (ADC), which receives analog signals and converts them into digital data for output. The ADC is a circuit that bridges external analog signals with digital signals that can be processed by the MCU.

There are various types of ADCs, such as successive approximation and sigma delta, but generally the type of ADC is chosen depending on the application requirements. Each type has the same main function and converts the input voltage signal to the corresponding number of bits. Figure 5 explains the basic operation principle of the successive approximation ADC and sigma delta ADC.



**Figure 5:** Basic principles of successive approximation ADC and sigma delta ADC

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## Successive Approximation ADC

Successive approximation ADC is a technology widely used for 10-bit or 12-bit ADCs built into common MCUs. The N-bit resolution successive approximation ADC contains an N-bit DAC that compares the analog input signal to the DAC output from half the analog reference level until the least significant bit is reached. Normally, the overall conversion time is calculated by adding the sampling time to the comparison time. These times are usually in the order of several microseconds, and the advantage is that the conversion is faster than the sigma delta ADC described below. On the other hand, it is not easy to create a high-resolution successive approximation ADC because the resolution of the successive approximation ADC is limited by the resolution of the DAC.

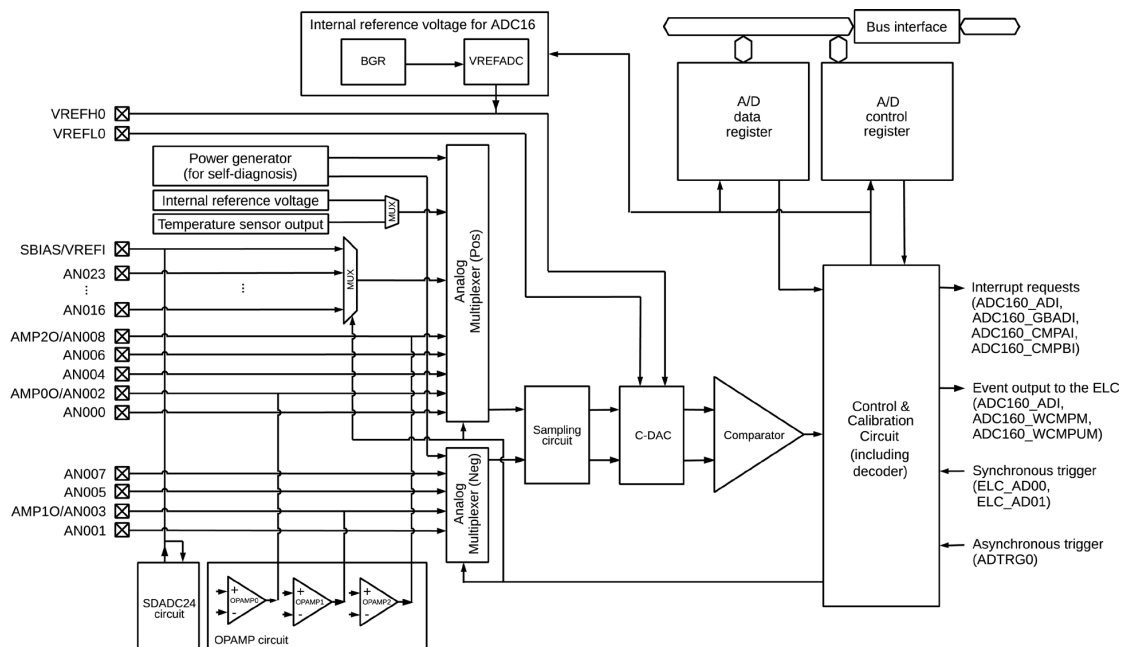
## Sigma Delta ADC

The sigma delta ADC has an integrator equivalent to sigma and a DAC equivalent to delta. The sigma delta ADC first captures an analog input, uses an integrator to hold the analog input voltage, and then compares it to the reference voltage. If the voltage at the integrator output is lower than the reference value, the comparator outputs zero, the result is received, and the 1-bit DAC outputs the negative side of the reference voltage. This is fed back to the next stage of the analog input as a subtraction. This analog input is then added to the previous voltage level held in the integrator and compared again to the reference value. If the analog voltage level is higher than the reference value, the comparator outputs 1 and the 1-bit DAC outputs the positive side of the reference voltage. Then, it is fed back to the next stage of the analog input as a subtraction again. This iteration results in a 1-bit sigma-delta modulator outputting 1 and 0, and an AD conversion result is a ratio of 1 to all counts of both 1 and 0. The sigma delta ADC uses only a single-bit DAC for easy resolution and excellent linearity. On the other hand, the conversion time is usually slower than the successive approximation ADC because it requires more sampling or oversampling to obtain high resolution and low noise results.

This document describes the features of the successive approximation ADC and sigma delta ADC on RA2A1.

## RA2A1 16-Bit Successive Approximation ADC

RA2A1 has a 16-bit successive approximation AD converter (ADC16). Figure 6 is a block diagram of ADC16, and Table 1 shows an outline of the specifications.



**Figure 6:** Block diagram of 16-bit successive approximation ADC of RA2A1

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ADC16 can have up to 17 single-ended inputs or up to 4 differential inputs. Reference voltages can also be generated internally in the MCUs. 1.5V, 2V, and 2.5V can be selected. A wide range of reference

voltages can be selected inside the MCU, eliminating the need for the user to build an external reference voltage circuit. RA2A1 also has an internal op-amp that can be interconnected by analog switches, allowing flexible signal-conditioning circuitry to be configured inside the MCUs. This eliminates external wiring that may compromise signal integrity, enabling the reduction of the number of external components and simplification of printed circuit boards.

Item	Reference value	Unit	For the conditions, refer to the user manual.
Resolution	16	Bit	
Integral nonlinearity error	$\pm 4$	LSB	
Differential nonlinearity error	-1 to +2	LSB	
ENOB	13.2	Bit	
Conversion time	0.82	$\mu\text{s}$ (per channel)	

**Table 1:** RA2A1 successive approximation ADCs overview1

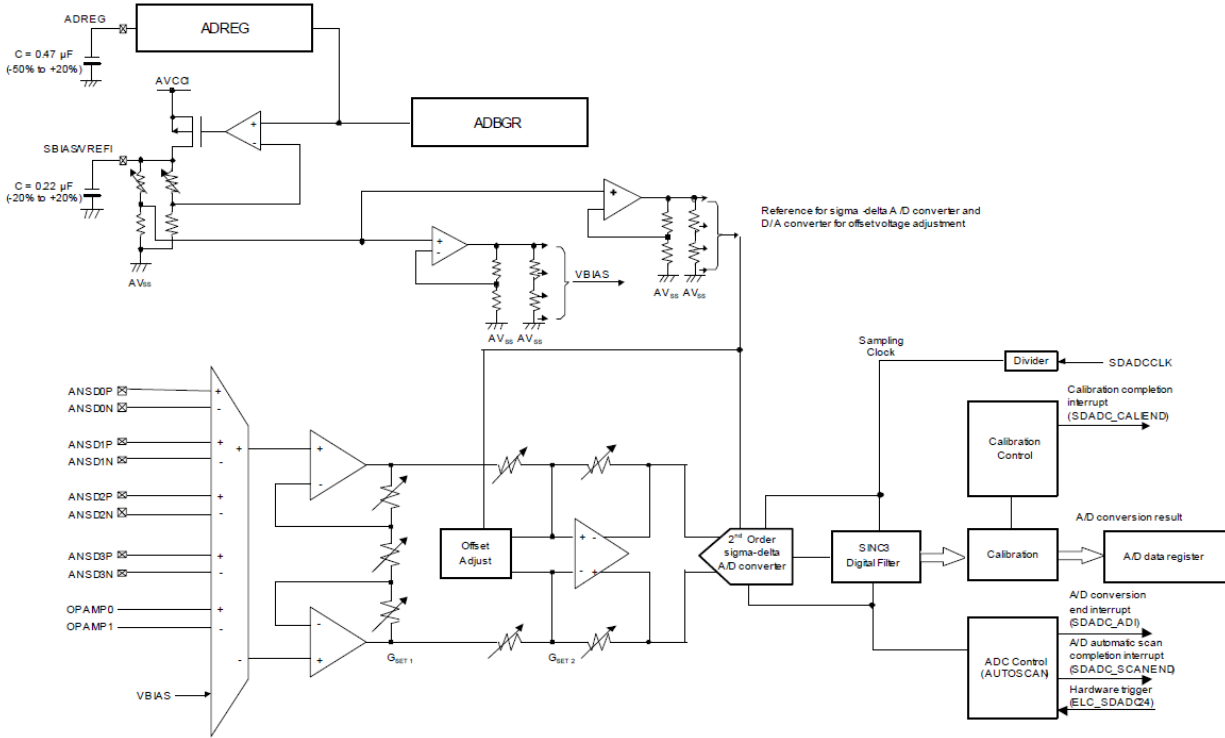
## RA2A1 24-Bit Sigma Delta ADCs

RA2A1 has up to 10 single-ended inputs or a 24-bit sigma delta ADC supporting up to 5 differential inputs. The internal reference voltage can be selected from 0.8V to 2.4V in 0.2V increments, providing flexibility for a variety of application requirements. In addition, the clock source of the ADC is generated from the MCU peripheral clock, thus eliminating the need for external clocks and reducing cost while increasing system reliability. Generally, discrete sigma delta ADC IC requires an external high-precision reference voltage circuit and an external clock. These external components complicate and add cost to the circuit design; however, RA2A1 MCUs also incorporate internal reference voltages and clock sources, which simplifies circuit design and reduces costs.

Low-power operation is also required for products with limited power supply, such as battery-powered products; however, the sigma delta ADC built into RA2A1 MCUs can also operate in low-power conversion mode using a reference clock between 125KHz and 500KHz. The clock supply at this time can also be realized using the divider in the MCU, so there is no need to input a low-frequency clock externally, enabling a more flexible and compact circuit design.

Figure 7 shows a block diagram of RA2A1 sigma delta ADCs, and Table 2 provides a specification summary.





**Figure 7:** Block diagram of 24-bit sigma delta ADCs in RA2A1 MCUs6

Item	Reference value	Unit	<b>For the conditions, refer to the user manual.</b>
<b>Resolution</b>	24	Bit	
<b>Oversampling frequency</b>	1 (Normal mode)	MHz	
<b>Output Data Rate</b>	0.48828 to 15.625	Ksps	
<b>Gain error</b>	-0.5 to 0.5	%	
<b>Gain lift</b>	6	Ppm/°C	
<b>Offset error</b>	-1 to 1	mV	
<b>Offset drift</b>	2	µV/°C	

**Table 2:** RA2A1 sigma delta ADCs overview2

In addition to the analog functions discussed so far, RA2A1 MCUs also include a variety of communication I/Fs, such as USB and CAN, and peripheral functions, such as robust security functions, high-sensitivity, and high-noise tolerance touch sensors. By combining these functions with analog functions, you can add security enhancements such as IoT measurement systems and secure firmware updates, and HMI with intuitive and high-design capabilities to realize a high-value-added measurement system.

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## Conclusion

Advances in process technology and design technology have made it possible to incorporate analog functions into MCUs, which were previously only feasible with external circuits that combine single components. RA2A1 MCUs highly integrate multi-functional, high-precision analog modules such as operational amplifiers, 16-bit successive approximation ADCs, and 24-bit sigma delta ADCs, all built into the MCU. As a result, the number of external components can be reduced to simplify designs, thereby improving the efficient development of measurement systems. Integrating a multi-functional, high-precision analog module into the MCU allows for a completely new application that combines analog and digital dynamically under user control.

## Learn More

1. [RA2A1 Product Page](#)
2. [RA Partner Ecosystem](#)
3. [Flexible Software Package \(FSP\)](#)
4. [RA Family of MCUs](#)

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