



AK9223

Dual 1-Bit, 10MHz, 2nd-Order, $\Delta\Sigma$ Modulator

General Description

The AK9223 is a 2ch delta-sigma modulator that achieves 86dB dynamic range. It operates of a 5V power supply. The AK9223 is available in a space-saving 24-pin TSSOP package.

Features

- Resolution: 16-bit
- Linearity: 13-bit
- Input Voltage Range: $\pm 2.3V$
- High Accurate Reference Voltage: $\pm 1\%$ ($2.5V \pm 0.025V$), $\pm 20ppm/^{\circ}C$ (typ.)
- Gain Error: 0.5% (max.)
- 2ch $\Delta\Sigma$ Modulator
- 2ch Input Reference
- 20MHz OSC
- Selectable External Clocks
- Power Consumption: 67.5 mW (SEL=1, AVDD = DVDD = 5V)
- Power Supply: AVDD = 4.5 to 5.5V, DVDD = 2.7 to 5.5V
- Ta = -40 to 105 $^{\circ}C$
- Small Package: 24-pin TSSOP (0.65mm pitch)

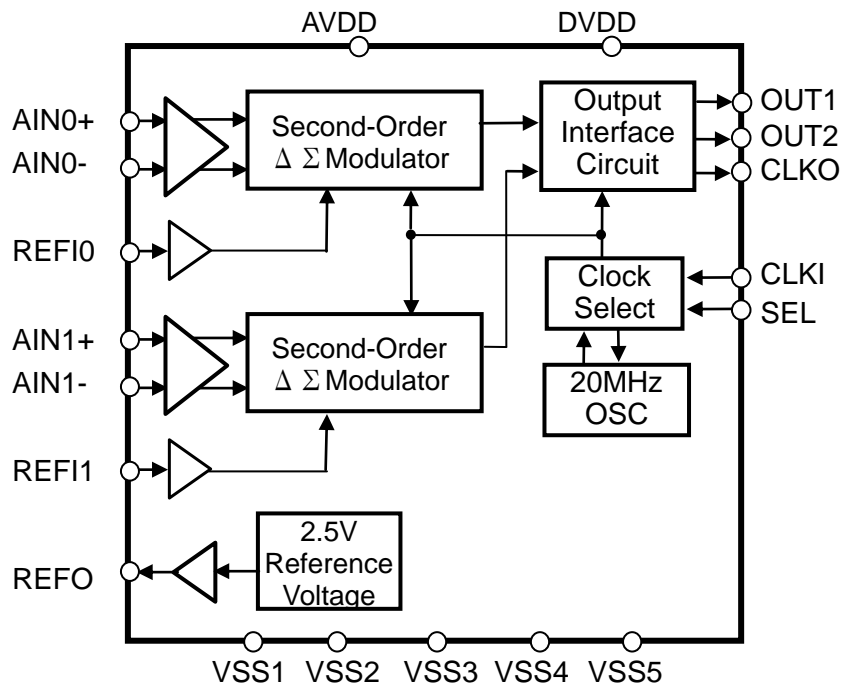
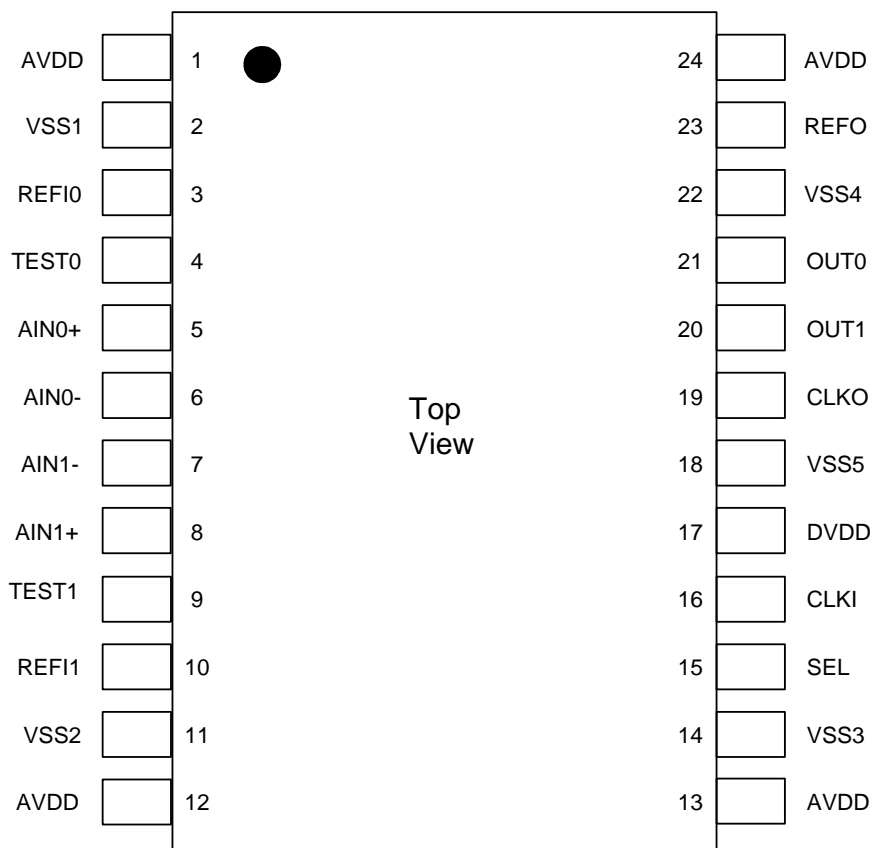


Figure 1. Block Diagram

■ Pin Configurations



Pin Functions

Pin No.	Pin Name	I/O	Function
1	AVDD	-	Analog Power Supply: 4.5V to 5.5V Connect to VSS1~VSS4 with a 0.1μF ceramic capacitor.
2	VSS1	-	Ground
3	REFI0	I	Reference Voltage input for Channel 0
4	TEST0	-	TEST Pin. This pin must be open.
5	AIN0+	I	Channel 0 Analog input+
6	AIN0-	I	Channel 0 Analog input-
7	AIN1-	I	Channel 1 Analog input-
8	AIN1+	I	Channel 1 Analog input+
9	TEST1	-	TEST Pin. This pin must be open.
10	REFI1	I	Reference Voltage input for Channel 1
11	VSS2	-	Ground
12	AVDD	-	Analog Power Supply: 4.5V to 5.5V Connect to VSS1~VSS4 with a 0.1μF ceramic capacitor.
13	AVDD	-	Analog Power Supply: 4.5V to 5.5V Connect to VSS1~VSS4 with a 0.1μF ceramic capacitor.
14	VSS3	-	Ground
15	SEL	I	Clock select input “H”: internal oscillator, “L”: external clock source
16	CLKI	I	External clock input If not used, must be tied to DVDD or VSS5
17	DVDD	-	Digital Power Supply: 2.7 V to 3.6V (or 4.5V to 5.5V) Connect to VSS5 with a 0.1μF ceramic capacitor.
18	VSS5	-	Ground
19	CLKO	O	Clock output
20	OUT1	O	Data output of Channel 1 modulator
21	OUT0	O	Data output of Channel 0 modulator
22	VSS4	-	Ground
23	REFO	O	Reference Voltage output for Channel 0 and Channel 1
24	AVDD	-	Analog Power Supply: 4.5V to 5.5V Connect to VSS1~VSS4 with a 0.1μF ceramic capacitor.

Note 1. Digital input pins (SEL, CLKI) must not be allowed to float.

■ Handling of Unused Pin

Unused I/O pins must be connected appropriately.

Classification	Pin Name	Setting
Analog	AIN0+, AIN0-, AN1+, AIN1-, REFI0, REFI1	VSS

Absolute Maximum Ratings

(VSS1~VSS5 = 0V; Note 2, Note 3)

Parameter	Symbol	Min.	Max.	Unit
Power Supply	VDD	-0.3	+6.0	V
Analog Input Current (AIN0+, AIN0-, AIN1+, AIN1-, REF10, REF11)	AIIN	-	±10	mA
Analog Input Voltage (AIN0+, AIN0-, AIN1+, AIN1-, REF10, REF11)	AVIN	-0.3	AVDD+0.3	V
Digital Input Current (CLKI, SEL)	DIIN	-	±10	mA
Digital Input Voltage (CLKI, SEL)	DVIN	-0.3	DVDD+0.3	V
Storage Temperature	Tstg	-65	150	°C

WARNING: Operation at or beyond these limits may result in permanent damage to the device.
Normal operation is not guaranteed at these extremes.

Recommended Operating Conditions

(VSS1~VSS5 = 0V; Note 2, Note 3)

Parameter	Symbol	Min.	Typ.	Max.	Unit	
Analog Power Supply	AVDD	4.5	5.0	5.5	V	
Digital Power Supply	DVDD	3V logic level	2.7	3.0	3.6	V
		5V logic level	4.5	5	5.5	V
Input Reference Voltage	REFI	0.5	2.5	2.6	V	
Analog Input	V _{in} = (AIN+) - (AIN-)	-0.92 x VREF		+0.92 x VREF	V	
External clock		16	20	24	MHz	
Ambient Operating Temperature	T _a	-40		105	°C	

Note 2. All voltages are with respect to ground.

Note 3. VSS1, VSS2, VSS3, VSS4 and VSS5 must be connected to the same analog ground plane.

Note 4. The power supply sequence between AVDD and DVDD is not critical upon power-up.

* AKM assumes no responsibility for the usage beyond the conditions in this datasheet.

Analog Characteristics

(Ta = -40°C to 105°C; AVDD=5V, DVDD=3V, AIN+=0.2V to 4.8V, AIN-=2.5V, REFI=REFO=2.5V (internal), CLKI= 20MHz, and 16bit Sinc³ filter with OSR =256; unless otherwise specified)

Parameter		Min.	Typ.	Max.	Unit
Resolution		16	-	-	Bits
Integral Nonlinearity (INL) Error (Note 5)	VIN = ±2.3Vpp	-8	±3.8	+8	LSB
	VIN = ±2.0Vpp	-4	±1.8	+4	LSB
Integral Nonlinearity Match		-	1	4	LSB
Differential Nonlinearity (DNL) Error		-1	-	+1	LSB
Offset Error	REFI=2.5V	-3	±1.5	+3	mV
Offset Error Match		-	0.2	2	mV
Offset Error Drift	(Note 6)	-8	1	+8	μV /°C
Gain Error	(Note 7) Referenced REFI = 2.5V	-0.5	±0.02	+0.5	%FSR
Gain Error Match		-	0.1	0.5	%FSR
Gain Error Drift	(Note 8)	-	±1.3	-	ppm/°C
PSRR		-	82	-	dB
Analog Input					
Full scale Differential Input Voltage Range:	(AIN+)-(AIN-) AIN- =2.5V	-REFI	-	+REFI	V
Specified Differential Input Voltage Range	(AIN+)-(AIN-) AIN- =2.5V	-0.92 x REFI	-	+0.92 x REFI	V
Absolute Input Voltage Range		0	-	AVDD	V
Input Capacitance	AIN to VSS	-	1	-	pF
Input Leakage Current	Clock turned off (Note 9)	-1	-	+1	μA
Differential Input Resistance		80	100	120	kΩ
Differential Input Capacitance		-	2.5	-	pF
CMRR AIN- =2.5V	at dc	-	108	-	dB
	Vin = ±1.25Vpp at 40kHz	-	117	-	dB
Sampling Dynamics					
Internal Clock Frequency	SEL=1, -40°C to +105°C	9	10	11	MHz
External Clock Frequency	SEL=0 (Note 10)	1	20	24	MHz
Dynamic Characteristics					
THD	Vin = ±2.3Vpp at 5kHz	-	-85	-80	dB
SFDR	Vin = ±2.3Vpp at 5kHz	82	86	-	dB
S/N	Vin = ±2.3Vpp at 5kHz	88	92	-	dB
	Vin = ±2.0Vpp at 5kHz	87	91	-	dB
S/(N+D)	Vin = ±2.3Vpp at 5kHz	80	84	-	dB
Channel to Channel Isolation	Vin = ±2.3Vpp at 5kHz	-	100	-	dB

Note 5. Integral nonlinearity is defined as the maximum deviation of the line through the end points of the specified input range.

Note 6. This is the maximum variation referring the offset of Ta = 25°C when the temperature range is from -40 to 105°C.

Note 7. Referring the REFI pin (It does not include internal VREF variation)

Note 8. This value does not include temperature drift of the internal VREF.

Note 9. Outgoing current from the AK9223 is defined as “-” polarity.

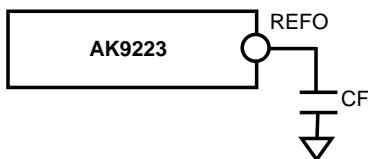
Note 10. Recommended input range of the external clock is from 16MHz to 24MHz. The range of 1MHz~16MHz and 24MHz~32MHz can also be available with reduced accuracy.

Analog Characteristics

(Ta = -40°C to 105°C; AVDD=5V, DVDD=3V, AIN+=0.2V to 4.8V, AIN-=2.5V, REFIx=REFO=2.5V (internal), CLKI= 20MHz, and 16bit Sinc³ filter with OSR =256; unless otherwise specified)

Parameter	Min.	Typ.	Max.	Unit	
Reference Voltage Output					
Reference output voltage	2.475	2.5	2.525	V	
Reference output voltage drift		±20		ppm/°C	
Output current		10		μA	
Short-circuit current		0.5		mA	
Turn-on settling time	CF = 0.1μF (Note 11)	500		μs	
Reference Voltage Input					
Reference input voltage	0.5	2.5	2.6	V	
Input resistance		100		MΩ	
Input capacitance		5		pF	
Input current			1	μA	
Power Supplies					
AIDD	SEL=1		12.2	17	mA
	SEL=0		11.8	16	mA
DIDD	DVDD=3V, CLKO = 10MHz		0.9	2	mA
	DVDD=5V, CLKO = 10MHz		1.3	3	mA

Note 11. To accuracy level of 0.1%. This value will be 40μs (typ) when no load.



DC Characteristics

(Ta = -40°C to 105°C, AVDD=4.5V to 5.5V, DVDD=2.7V to 5.5V)

Parameter	Symbol	Min.	Typ.	Max.	Unit
High-Level Input Voltage1, DVDD=2.7V to 3.6V	VIH1	2		-	V
Low-Level Input Voltage1, DVDD=2.7V to 3.6V	VIL1	-		0.8	V
High-Level Input Voltage2, DVDD=4.5V to 5.5V	VIH2	0.7 x DVDD	-	-	V
Low-Level Input Voltage2, DVDD=4.5V to 5.5V	VIL2	-	-	0.3 x DVDD	V
Input capacitance	Ic	-	5	-	pF
Input Leakage Current	Iin	-	-	±1	uA
High-Level Output Voltage , DVDD=4.5V (Iout = -100μA)	VOH2	4.44	-	-	V
Low-Level Output Voltage , DVDD=4.5V (Iout =100μA)	VOL2	-	-	0.5	V
High-Level Output Voltage , DVDD=2.7V (Iout = -100μA)	VOH1	DVDD-0.2	-	-	V
Low-Level Output Voltage , DVDD=2.7V (Iout =100μA)	VOL1	-	-	0.2	V
Output Capacitance	CO	-	5	-	pF
Load Capacitance	CL	-	-	30	pF

Switching Characteristics

(Ta = -40°C to 105°C, AVDD=5V, DVDD=2.7V to 5.5V, CL=30pF)

Parameter	Symbol	Min.	Typ.	Max.	Unit
CLKI period	tCKI	41.6		1000	ns
CLKI High Pulse Width	tCKH	10		tCKI-10	ns
CLKO period	SEL=0 tCKO1	2 x tCKI		111	ns
	SEL=1 tCKO2	91			ns
CLKO High Pulse Width	tCKOH	(tCKO/2) -5		(tCKO/2)+ 5	ns
CLKI "↑" to CLKO "↓" Delay	SEL=0 tPD1			10	ns
CLKI "↑" to CLKO "↑" Delay	SEL=0 tPD2			10	ns
CLKO "↑" to OUT data Delay	SEL=0 tPD3	tCKH-3		tCKH+7	ns
	SEL=1 tPD4	(tCKO/4)-8		(tCKO/4)+8	ns

■ Timing Diagram

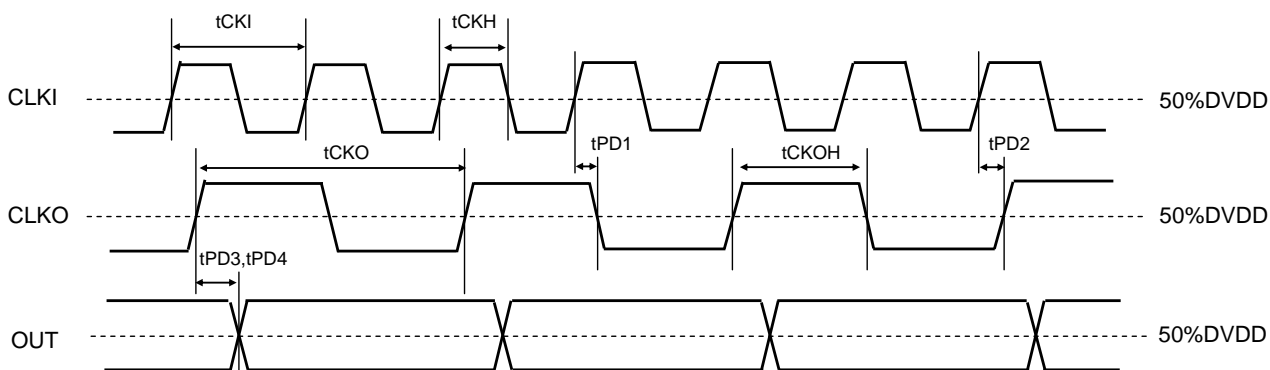


Figure 2. Data Output Timing

Functional Descriptions

The AK9223 is a 2ch delta-sigma modulator. "0" and "1" data is output from its OUT pins and the level of analog input signal is expressed by the density of this digital output.

A delta-sigma modulator shifts quantized noise to high band. A low-pass filter is needed at the output of the AK9223. High band noise is filtered and the 1-bit data stream at a high sampling rate is converted into a higher-bit data word at a lower rate by this low-pass filter (decimation). This digital filter can be composed by a FPGA and etc. [Figure 3](#) shows external circuit example. Recommended parts shown below should be connected as close as possible to the device.

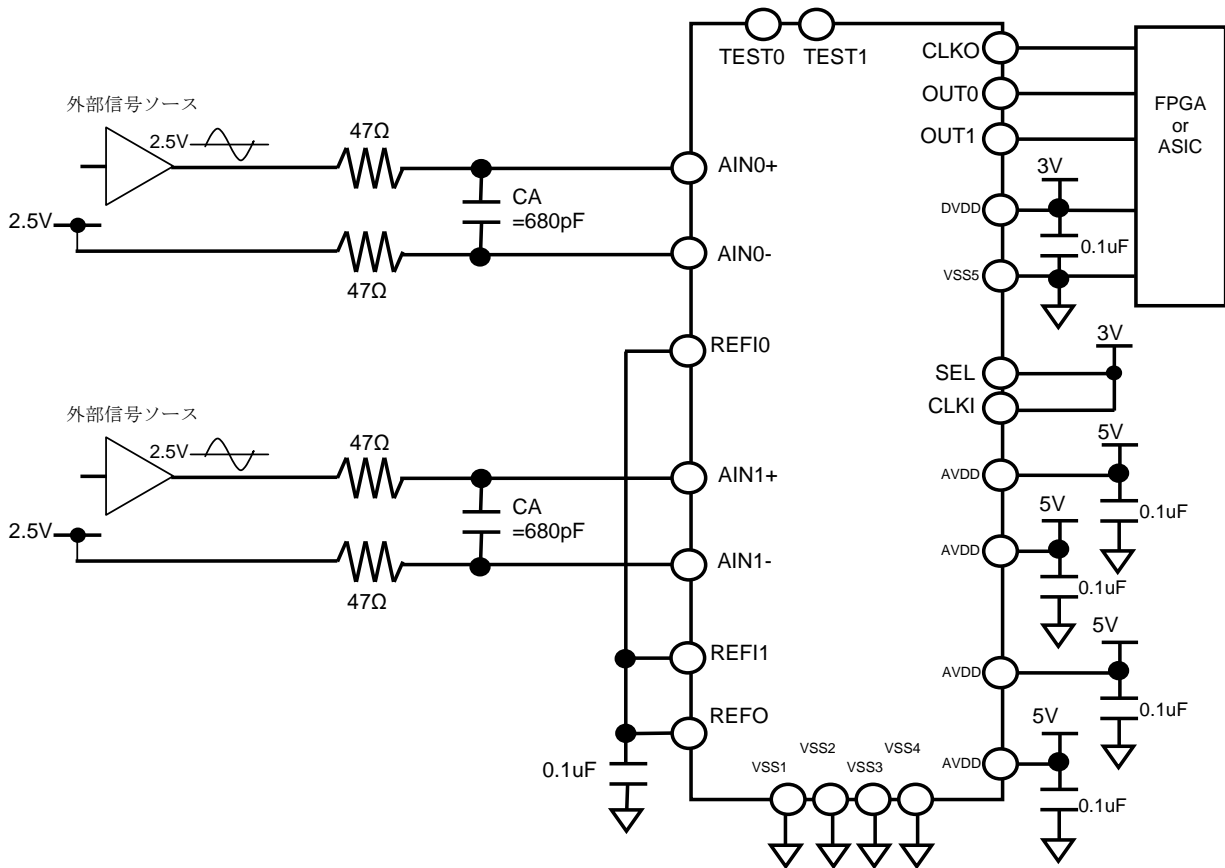


Figure 3. AK9223 Recommended External Circuits

AD conversion characteristics (speed and accuracy) are dependent on OSR (over sampling ratio) and digital filter type. When the conversion rate is low, greater output accuracy can be achieved by increasing the OSR. When the OSR is low, output accuracy is low but high speed conversion is available. With an appropriate digital filter, the AK9223 is capable of AD conversion results that have a dynamic range exceeding 86dB with an OSR = 256.

■ Internal Operation

The analog input of the AK9223 is composed by SC (switched-capacitor) circuits and this modulator block digitizes analog inputs to 1-bit data stream. The clock source can be external or internal oscillator output. Analog input is sampled by the modulator and compared with the reference voltage of the REF1 pin. A digital stream that represents the analog input voltage over time appears at the output of the corresponding converter.

■ Modulator

The AK9223 can be operated in two modes. Internal oscillation is used for the operation clock of the modulator by setting the SEL pin = "H". In this case, the internal clock is fixed to 20MHz. When the SEL pin is set to "L", modulator clock is externally input to the CLKI pin. In both of modes, the clock is internally divided by two and functions as the modulator clock. When using an external clock, available input clock range is from 1MHz to 24MHz. In this case, the modulator operates of a clock from 500kHz to 12MHz.

■ Digital I/F

Analog input signals are converted with the modulator input clock. The OUT pin outputs the result of AD conversion. The common clock that is used for two modulators is output from the CLKO pin. When the SEL pin = "H", the CLKI pin must not be allowed to float but should be connected to DVDD or VSS5.

■ Digital Filter

Digital data stream is output from the modulator. This data stream should be processed by a digital filter to obtain an equivalent digital data to the analog input. Transfer function of the simple Sinc³ filter is shown below.

$$H(z) = \left(\frac{1 - z^{-OSR}}{1 - z^{-1}} \right)^3$$

This filter provides the best output performance with a relatively low number of gates required for implementation. All the characterizations in this datasheet are done using a Sinc³ filter (OSR = 256, Output Word Width: 16 bits).

Figure 4 and Figure 5 show the filter characteristics. The location of the first notch is fDATA (=fMOD / OSR). The -3dB point is located at half the Nyquist frequency or fDATA/4.

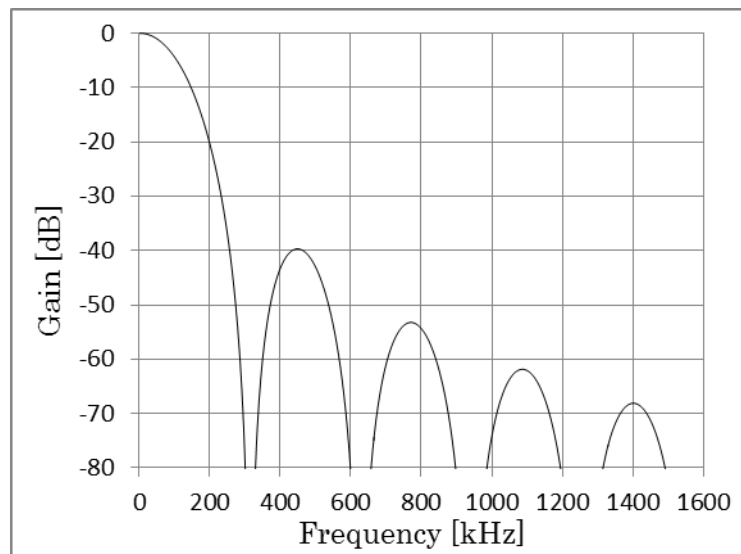


Figure 4. Sinc³ Frequency Characteristics (OSR=32)

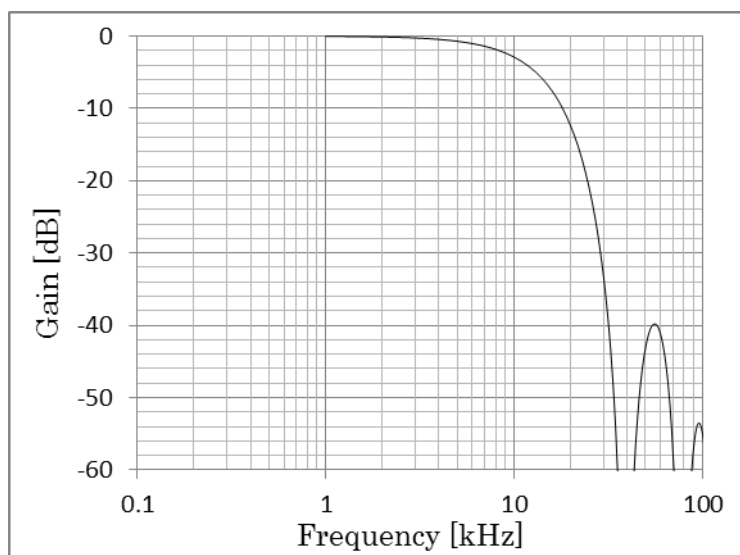


Figure 5. Sinc³ Frequency Characteristics (OSR=256)

System Design

■ Power Supply

Digital power supply determines the I/O interface voltage. It ranges from 2.7V to 5.5V. Inputs to the AK9223, such as AIN+, AIN- and CLKI pins should not be present before the power supply is on.

■ Decoupling

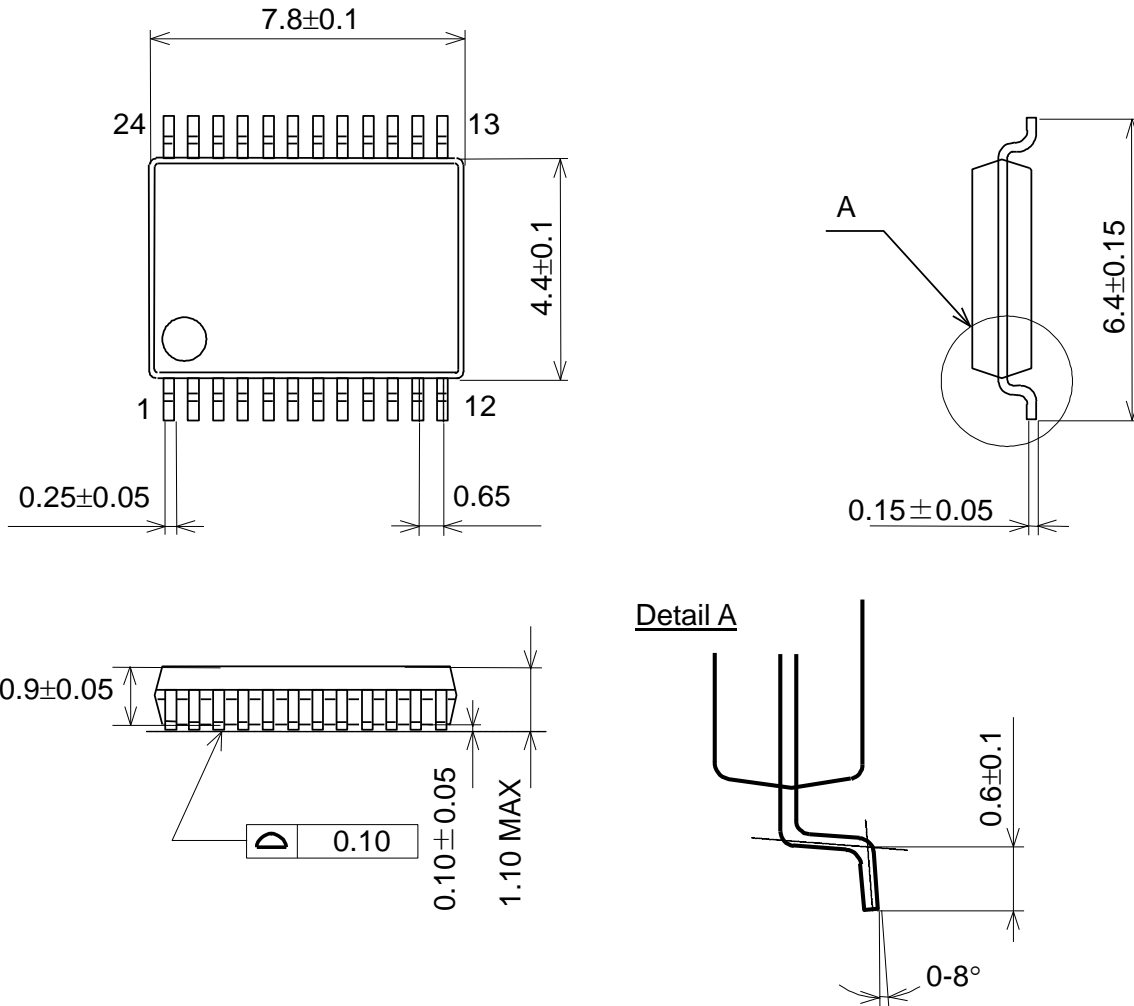
A decoupling capacitor should be connected to the pin as close as possible. A 0.1 μ F ceramic capacitor should be connected between AVDD (Pin #1) and VSS1, AVDD (Pin #12) and VSS2, AVDD (Pin #13) and VSS3, AVDD (Pin #24) and VSS4, and DVDD and VSS5.

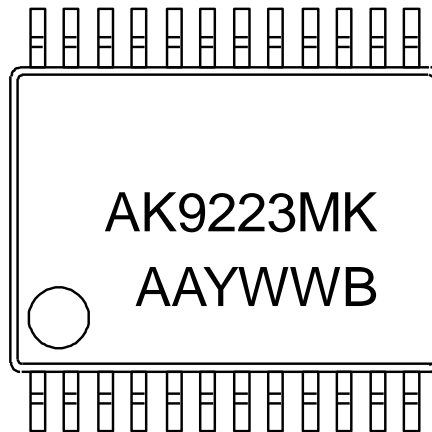
If the analog and digital I/O powers are drawn from the same source, connect a 10 Ω resistor between the analog and digital power supply pins, and connect the power source to the analog power supply pin. An RC filter should be composed by this 10 Ω resistor and a 0.1 μ F capacitor to reduce noises in the analog supply.

Package

■ Outline Dimensions

24-pin TSSOP (Unit: mm)



■ **Marking**

- a. Pin #1 Indication
- b. Product Name: AK9223MK
- c. Date Code: AAYWWB

AA : Administration Code 2digits
Y : Year 1digit
WW : Week 2digits
B : Administration Code 1digit

Ordering Guide

■ **Ordering Guide**

AK9223MK

-40 ~ +105°C

24-pin TSSOP (0.65mm pitch)

Revision History

Date (Y/M/D)	Revision	Reason	Page	Contents
15/01/15	00	First Edition		
15/07/29	01		p.3	(Pin No.7) Pin Name : AIN1+ Function : Channel 1 Analog input+ ↓ Pin Name : AIN1- Function : Channel 1 Analog input- (Pin No.8) Pin Name : AIN1- Function : Channel 1 Analog input- ↓ Pin Name : AIN1+ Function : Channel 1 Analog input+
19/02/01	02		p.3	(Pin No.23) Pin Name : REF0 I/O: I ↓ Pin Name : REFO I/O: O (Pin No.23) Function : Reference Voltage input for Channel 0 ↓ Function : Reference Voltage output for Channel 0 and Channel 1

IMPORTANT NOTICE

0. Asahi Kasei Microdevices Corporation ("AKM") reserves the right to make changes to the information contained in this document without notice. When you consider any use or application of AKM product stipulated in this document ("Product"), please make inquiries the sales office of AKM or authorized distributors as to current status of the Products.
1. All information included in this document are provided only to illustrate the operation and application examples of AKM Products. AKM neither makes warranties or representations with respect to the accuracy or completeness of the information contained in this document nor grants any license to any intellectual property rights or any other rights of AKM or any third party with respect to the information in this document. You are fully responsible for use of such information contained in this document in your product design or applications. **AKM ASSUMES NO LIABILITY FOR ANY LOSSES INCURRED BY YOU OR THIRD PARTIES ARISING FROM THE USE OF SUCH INFORMATION IN YOUR PRODUCT DESIGN OR APPLICATIONS.**
2. The Product is neither intended nor warranted for use in equipment or systems that require extraordinarily high levels of quality and/or reliability and/or a malfunction or failure of which may cause loss of human life, bodily injury, serious property damage or serious public impact, including but not limited to, equipment used in nuclear facilities, equipment used in the aerospace industry, medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, devices related to electric power, and equipment used in finance-related fields. Do not use Product for the above use unless specifically agreed by AKM in writing.
3. Though AKM works continually to improve the Product's quality and reliability, you are responsible for complying with safety standards and for providing adequate designs and safeguards for your hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of the Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption.
4. Do not use or otherwise make available the Product or related technology or any information contained in this document for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). When exporting the Products or related technology or any information contained in this document, you should comply with the applicable export control laws and regulations and follow the procedures required by such laws and regulations. The Products and related technology may not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations.
5. Please contact AKM sales representative for details as to environmental matters such as the RoHS compatibility of the Product. Please use the Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. AKM assumes no liability for damages or losses occurring as a result of noncompliance with applicable laws and regulations.
6. Resale of the Product with provisions different from the statement and/or technical features set forth in this document shall immediately void any warranty granted by AKM for the Product and shall not create or extend in any manner whatsoever, any liability of AKM.
7. This document may not be reproduced or duplicated, in any form, in whole or in part, without prior written consent of AKM.