

ADC161S626

16-Bit, 50 to 250 kSPS, Differential Input, MicroPower ADC

General Description

The ADC161S626 is a 16-bit successive-approximation register (SAR) Analog-to-Digital converter (ADC) with a maximum sampling rate of 250 kSPS. The ADC161S626 has a minimum signal span accuracy of $\pm 0.003\%$ over the temperature range of -40°C to $+85^{\circ}\text{C}$. The converter features a differential analog input with an excellent common-mode signal rejection ratio of 85 dB, making the ADC161S626 suitable for noisy environments.

The ADC161S626 operates with a single analog supply (V_A) and a separate digital input/output (V_{IO}) supply. V_A can range from $+4.5\text{V}$ to $+5.5\text{V}$ and V_{IO} can range from $+2.7\text{V}$ to $+5.5\text{V}$. This allows a system designer to maximize performance and minimize power consumption by operating the analog portion of the ADC at a V_A of $+5\text{V}$ while interfacing with a $+3.3\text{V}$ controller. The serial data output is binary 2's complement and is SPI™ compatible.

The performance of the ADC161S626 is guaranteed over temperature at clock rates of 1 MHz to 5 MHz and reference voltages of $+2.5\text{V}$ to $+5.5\text{V}$. The ADC161S626 is available in a small 10-lead MSOP package. The high accuracy, differential input, low power consumption, and small size make the ADC161S626 ideal for direct connection to bridge sensors and transducers in battery operated systems or remote data acquisition applications.

Applications

- Direct Sensor Interface
- I/O Modules
- Data Acquisition
- Portable Systems
- Motor Control
- Medical Instruments
- Instrumentation and Control Systems

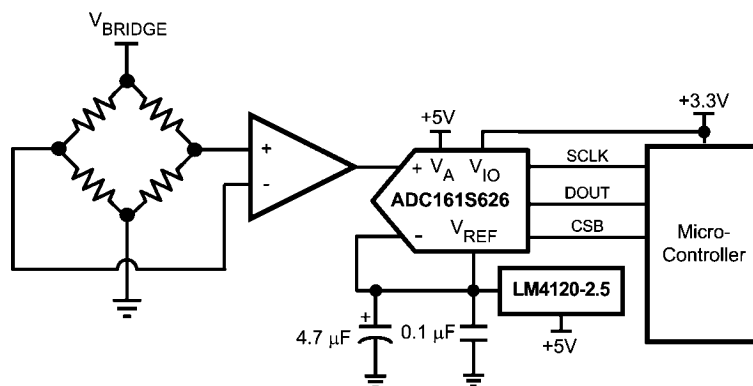
Features

- 16-bit resolution with no missing codes
- Guaranteed performance from 50 to 250 kSPS
- $\pm 0.003\%$ signal span accuracy
- Separate Digital Input/Output Supply
- True differential input
- External voltage reference range of $+0.5\text{V}$ to V_A
- Zero-Power Track Mode with 0 μsec wake-up delay
- Wide input common-mode voltage range of 0V to V_A
- SPI™/QSPI™/MICROWIRE™ compatible Serial Interface
- Operating temperature range of -40°C to $+85^{\circ}\text{C}$
- Small MSOP-10 package

Key Specifications

■ Conversion Rate	50 kSPS to 250 kSPS
■ DNL	$+ 0.8 / - 0.5$ LSB
■ INL	± 0.8 LSB
■ Offset Error Temp Drift	$2.5 \mu\text{V}/^{\circ}\text{C}$
■ Gain Error Temp Drift	$0.3 \text{ ppm}/^{\circ}\text{C}$
■ SNR	93.2 dBc
■ THD	$- 104 \text{ dBc}$
■ Power Consumption	
■ — 10 kSPS, 5V	0.24 mW
■ — 200 kSPS, 5V	5.3 mW
■ — 250 kSPS, 5V	5.8 mW
■ — Power-Down, 5V	10 μW

Typical Application



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Absolute Maximum Ratings (Notes 1, 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Analog Supply Voltage V_A	-0.3V to 6.5V
Digital I/O Supply Voltage V_{IO}	-0.3V to 6.5V
Voltage on Any Analog Input Pin to GND	-0.3V to ($V_A + 0.3V$)
Voltage on Any Digital Input Pin to GND	-0.3V to ($V_{IO} + 0.3V$)
Input Current at Any Pin (Note 3)	± 10 mA
Package Input Current (Note 3)	± 50 mA
Power Consumption at $T_A = 25^\circ\text{C}$	See (Note 4)
ESD Susceptibility (Note 5)	
Human Body Model	2500V
Machine Model	250V
Charge Device Model	1250V
Junction Temperature	$+150^\circ\text{C}$
Storage Temperature	-65°C to $+150^\circ\text{C}$

Operating Ratings (Notes 1, 2)

Operating Temperature Range	$-40^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$
Supply Voltage, V_A	+4.5V to +5.5V
Supply Voltage, V_{IO}	+2.7V to +5.5V
Reference Voltage, V_{REF}	+0.5V to V_A
Analog Input Pins Voltage Range	0V to V_A
Differential Analog Input Voltage	$-V_{REF}$ to $+V_{REF}$
Input Common-Mode Voltage, V_{CM}	See Figure 10 (Sect 2.3)
Digital Input Pins Voltage Range	0V to V_{IO}
Clock Frequency	1 MHz to 5 MHz

Package Thermal Resistance

Package	θ_{JA}
10-lead MSOP	$240^\circ\text{C} / \text{W}$

Soldering process must comply with National Semiconductor's Reflow Temperature Profile specifications. Refer to www.national.com/packaging. (Note 6)

ADC161S626 Converter Electrical Characteristics (Note 7)

The following specifications apply for $V_A = 4.5V$ to $5.5V$, $V_{IO} = 2.7V$ to $5.5V$, and $V_{REF} = 2.5V$ to $5.5V$ for $f_{SCLK} = 1$ MHz to 4 MHz or $V_{REF} = 4.5V$ to $5.5V$ for $f_{SCLK} = 1$ MHz to 5 MHz; $f_{IN} = 20$ kHz, and $C_L = 25$ pF, unless otherwise noted. Maximum and minimum values apply for $T_A = T_{MIN}$ to T_{MAX} ; the typical values are tested at $T_A = 25^\circ\text{C}$.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
STATIC CONVERTER CHARACTERISTICS						
	Resolution with No Missing Codes				16	Bits
DNL	Differential Non-Linearity		-1	-0.5/+0.8	+2	LSB
INL	Integral Non-Linearity		-2	± 0.8	+2	LSB
OE	Offset Error	$V_{REF} = 2.5V$	-1	-0.1	+1	mV
		$V_{REF} = 5V$		-0.4		mV
OE _{DRIFT}	Offset Error Temperature Drift	$V_{REF} = 2.5V$		3.7		$\mu\text{V}/^\circ\text{C}$
		$V_{REF} = 5V$		2.5		$\mu\text{V}/^\circ\text{C}$
FSE	Positive Full-Scale Error			-0.003	± 0.03	%FS
	Negative Full-Scale Error			-0.002	± 0.03	%FS
GE	Positive Gain Error			-0.002	± 0.02	%FS
	Negative Gain Error			-0.0001	± 0.02	%FS
GE _{DRIFT}	Gain Error Temperature Drift			0.3		$\text{ppm}/^\circ\text{C}$
DYNAMIC CONVERTER CHARACTERISTICS						
SINAD	Signal-to-Noise Plus Distortion Ratio	$V_{REF} = 2.5V$	85	88		dBc
		$V_{REF} = 4.5V$ to $5.5V$	89	93.0		dBc
SNR	Signal-to-Noise Ratio	$V_{REF} = 2.5V$	85	88		dBc
		$V_{REF} = 4.5V$ to $5.5V$	89	93.2		dBc
THD	Total Harmonic Distortion	$V_{REF} = 2.5V$		-104		dBc
		$V_{REF} = 4.5V$ to $5.5V$		-106		dBc
SFDR	Spurious-Free Dynamic Range	$V_{REF} = 2.5V$		108		dBc
		$V_{REF} = 4.5V$ to $5.5V$		111		dBc
ENOB	Effective Number of Bits	$V_{REF} = 2.5V$	13.8	14.3		bits
		$V_{REF} = 4.5V$ to $5.5V$	14.5	15.2		bits
FPBW	-3 dB Full Power Bandwidth	Output at 70.7%FS with FS Differential Input		26		MHz

Symbol	Parameter	Conditions	Min	Typ	Max	Units
ANALOG INPUT CHARACTERISTICS						
V _{IN}	Differential Input Range		−V _{REF}		+V _{REF}	V
I _{INA}	Analog Input Current	C _S high			±1	μA
		V _{REF} = 5V, V _{IN} = 0V, f _S = 50 kSPS		3.2		nA
		V _{REF} = 5V, V _{IN} = 0V, f _S = 200 kSPS		10.3		nA
C _{INA}	Input Capacitance (+IN or −IN)	In Acquisition Mode		20		pF
		In Conversion Mode		4		pF
CMRR	Common Mode Rejection Ratio	See the Specification Definitions for the test condition		85		dB
DIGITAL INPUT CHARACTERISTICS						
V _{IH}	Input High Voltage	f _{IN} = 0 Hz	0.7 × V _{IO}	1.9		V
V _{IL}	Input Low Voltage	f _{IN} = 0 Hz		1.7	0.3 × V _{IO}	V
I _{IND}	Digital Input Current				±1	μA
C _{IND}	Input Capacitance				4	pF
DIGITAL OUTPUT CHARACTERISTICS						
V _{OH}	Output High Voltage	I _{SOURCE} = 200 μA	V _{IO} − 0.2	V _{IO} − 0.03		V
		I _{SOURCE} = 1 mA		V _{IO} − 0.09		V
V _{OL}	Output Low Voltage	I _{SOURCE} = 200 μA		0.01	0.4	V
		I _{SOURCE} = 1 mA		0.07		V
I _{OZH} , I _{OZL}	TRI-STATE Leakage Current	Force 0V or V _A			±1	μA
C _{OUT}	TRI-STATE Output Capacitance	Force 0V or V _A		4		pF
	Output Coding			Binary 2'S Complement		
POWER SUPPLY CHARACTERISTICS						
V _A	Analog Supply Voltage Range		4.5	5	5.5	V
V _{IO}	Digital Input/Output Supply Voltage Range	(Note 9)	2.7	3	5.5	V
V _{REF}	Reference Voltage Range		0.5	5	V _A	V
I _{VA} (Conv)	Analog Supply Current, Conversion Mode	V _A = 5V, f _{SCLK} = 4 MHz, f _S = 200 kSPS		1060		μA
		V _A = 5V, f _{SCLK} = 5 MHz, f _S = 250 kSPS		1160	1340	μA
I _{VIO} (Conv)	Digital I/O Supply Current, Conversion Mode	V _{IO} = 3V, f _{SCLK} = 4 MHz, f _S = 200 kSPS		80		μA
		V _{IO} = 3V, f _{SCLK} = 5 MHz, f _S = 250 kSPS		100		μA
I _{VREF} (Conv)	Reference Current, Conversion Mode	V _A = 5V, f _{SCLK} = 4 MHz, f _S = 200 kSPS		80		μA
		V _A = 5V, f _{SCLK} = 5 MHz, f _S = 250 kSPS		100	170	μA
I _{VA} (PD)	Analog Supply Current, Power Down Mode (C _S high)	f _{SCLK} = 5 MHz, V _A = 5V		7		μA
		f _{SCLK} = 0 Hz, V _A = 5V (Note 8)		2	3	μA
I _{VIO} (PD)	Digital I/O Supply Current, Power Down Mode (C _S high)	f _{SCLK} = 5 MHz, V _{IO} = 3V		1		μA
		f _{SCLK} = 0 Hz, V _{IO} = 3V (Note 8)		0.3	0.5	μA
I _{VREF} (PD)	Reference Current, Power Down Mode (C _S high)	f _{SCLK} = 5 MHz, V _{REF} = 5V		0.5		μA
		f _{SCLK} = 0 Hz, V _{REF} = 5V (Note 8)		0.5	0.7	μA
PWR (Conv)	Power Consumption, Conversion Mode	V _A = 5V, f _{SCLK} = 4 MHz, f _S = 200 kSPS, and f _{IN} = 20 kHz,		5.3		mW
		V _A = 5V, f _{SCLK} = 5 MHz, f _S = 250 kSPS, and f _{IN} = 20		5.8	6.7	mW

Symbol	Parameter	Conditions	Min	Typ	Max	Units
PWR (PD)	Power Consumption, Power Down Mode (\overline{CS} high)	$f_{SCLK} = 5 \text{ MHz}$, $V_A = 5.0V$ (Note 8)		35		μW
		$f_{SCLK} = 0 \text{ Hz}$, $V_A = 5.0V$ (Note 8)		10	15	μW
PSRR	Power Supply Rejection Ratio	See the Specification Definitions for the test condition		-78		dB

AC ELECTRICAL CHARACTERISTICS

f_{SCLK}	Maximum Clock Frequency		1		5	MHz
f_S	Maximum Sample Rate	(Note 10)	50		250	kSPS
t_{ACQ}	Acquisition/Track Time		600			ns
t_{CONV}	Conversion/Hold Time				17	SCLK cycles
t_{AD}	Aperture Delay	See the Specification Definitions		6		ns

ADC161S626 Timing Specifications (Note 7)

The following specifications apply for $V_A = 4.5V$ to $5.5V$, $V_{IO} = 2.7V$ to $5.5V$, $V_{REF} = 2.5V$ to $5.5V$, $f_{SCLK} = 1\text{Mz}$ to 5MHz , and $C_L = 25 \text{ pF}$, unless otherwise noted. Maximum and minimum values apply for $T_A = T_{MIN}$ to T_{MAX} ; the typical values are tested at $T_A = 25^\circ C$.

Symbol	Parameter	Min	Typ	Max	Units
t_{CSS}	\overline{CS} Setup Time prior to an SCLK rising edge	8	3		ns
t_{CSH}	\overline{CS} Hold Time after an SCLK rising edge	8	3		
t_{DH}	D_{OUT} Hold Time after an SCLK falling edge	6	11		ns
t_{DA}	D_{OUT} Access Time after an SCLK falling edge		18	41	ns
t_{DIS}	D_{OUT} Disable Time after the rising edge of \overline{CS} (Note 11)		20	30	ns
t_{CS}	Minimum \overline{CS} Pulse Width	20			ns
t_{EN}	D_{OUT} Enable Time after the 2nd falling edge of SCLK		20	70	ns
t_{CH}	SCLK High Time	20			ns
t_{CL}	SCLK Low Time	20			ns
t_r	D_{OUT} Rise Time		7		ns
t_f	D_{OUT} Fall Time		7		ns

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions. Operation of the device beyond the maximum Operating Ratings is not recommended.

Note 2: All voltages are measured with respect to GND = 0V, unless otherwise specified.

Note 3: When the input voltage at any pin exceeds the power supplies (that is, $V_{IN} < \text{GND}$ or $V_{IN} > V_A$), the current at that pin should be limited to 10 mA. The 50 mA maximum package input current rating limits the number of pins that can safely exceed the power supplies with an input current of 10 mA to five.

Note 4: The absolute maximum junction temperature (T_{Jmax}) for this device is $150^\circ C$. The maximum allowable power dissipation is dictated by T_{Jmax} , the junction-to-ambient thermal resistance (θ_{JA}), and the ambient temperature (T_A), and can be calculated using the formula $P_{DMAX} = (T_{Jmax} - T_A)/\theta_{JA}$. The values for maximum power dissipation listed above will be reached only when the ADC161S626 is operated in a severe fault condition (e.g. when input or output pins are driven beyond the power supply voltages, or the power supply polarity is reversed). Such conditions should always be avoided.

Note 5: Human body model is a 100 pF capacitor discharged through a 1.5 k Ω resistor. Machine model is a 220 pF capacitor discharged through 0 Ω . Charge device model simulates a pin slowly acquiring charge (such as from a device sliding down the feeder in an automated assembler) then rapidly being discharged.

Note 6: Reflow temperature profiles are different for lead-free packages.

Note 7: Typical values are at $T_J = 25^\circ C$ and represent most likely parametric norms. Test limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 8: This parameter is guaranteed by design and/or characterization and is not tested in production.

Note 9: The value of V_{IO} is independent of the value of V_A . For example, V_{IO} could be operating at 5.5V while V_A is operating at 4.5V or V_{IO} could be operating at 2.7V while V_A is operating at 5.5V.

Note 10: While the maximum sample rate is $f_{SCLK} / 20$, the actual sample rate may be lower than this by having the \overline{CS} rate slower than $f_{SCLK} / 20$.

Note 11: t_{DIS} is the time for D_{OUT} to change 10% while being loaded by the Timing Test Circuit.

Timing Diagrams

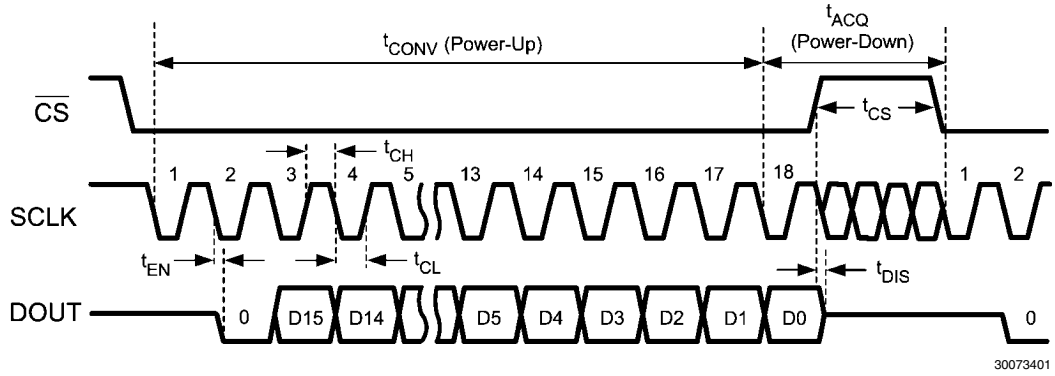


FIGURE 1. ADC161S626 Single Conversion Timing Diagram

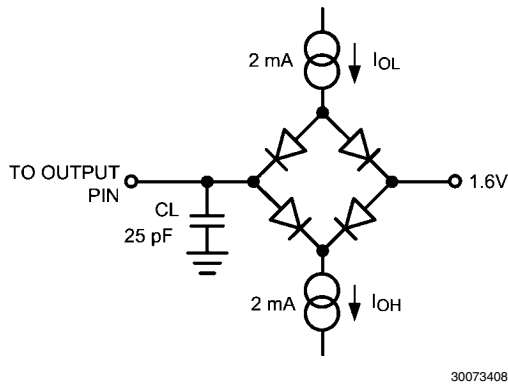


FIGURE 2. Timing Test Circuit



FIGURE 3. D_{OUT} Rise and Fall Times

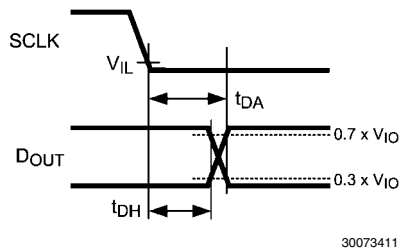


FIGURE 4. D_{OUT} Hold and Access Times

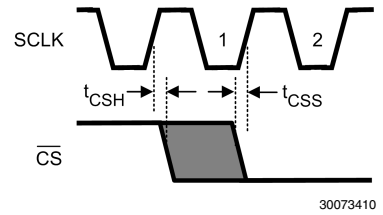


FIGURE 5. Valid $\overline{\text{CS}}$ Assertion Times

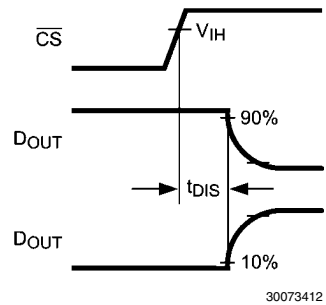


FIGURE 6. Voltage Waveform for t_{DIS}

Specification Definitions

APERTURE DELAY is the time between the first falling edge of SCLK and the time when the input signal is sampled for conversion.

COMMON MODE REJECTION RATIO (CMRR) is a measure of how well in-phase signals common to both input pins are rejected.

To calculate CMRR, the change in output offset is measured while the common mode input voltage is changed from 2V to 3V.

$$\text{CMRR} = 20 \text{ LOG} (\Delta \text{ Common Input} / \Delta \text{ Output Offset})$$

CONVERSION TIME is the time required, after the input voltage is acquired, for the ADC to convert the input voltage to a digital word.

DIFFERENTIAL NON-LINEARITY (DNL) is the measure of the maximum deviation from the ideal step size of 1 LSB.

DUTY CYCLE is the ratio of the time that a repetitive digital waveform is high to the total time of one period. The specification here refers to the SCLK.

EFFECTIVE NUMBER OF BITS (ENOB, or EFFECTIVE BITS) is another method of specifying Signal-to-Noise and Distortion or SINAD. ENOB is defined as $(\text{SINAD} - 1.76) / 6.02$ and says that the converter is equivalent to a perfect ADC of this (ENOB) number of bits.

FULL POWER BANDWIDTH is a measure of the frequency at which the reconstructed output fundamental drops 3 dB below its low frequency value for a full scale input.

GAIN ERROR is the deviation from the ideal slope of the transfer function. It is the difference between Positive Full-Scale Error and Negative Full-Scale Error and can be calculated as:

$$\text{Gain Error} = \text{Positive Full-Scale Error} - \text{Negative Full-Scale Error}$$

INTEGRAL NON-LINEARITY (INL) is a measure of the deviation of each individual code from a line drawn from $\frac{1}{2}$ LSB below the first code transition through $\frac{1}{2}$ LSB above the last code transition. The deviation of any given code from this straight line is measured from the center of that code value.

MISSING CODES are those output codes that will never appear at the ADC outputs. The ADC161S626 is guaranteed not to have any missing codes.

NEGATIVE FULL-SCALE ERROR is the difference between the differential input voltage at which the output code transitions from code 0x8001h to 0x8000h and $-V_{\text{REF}} + 1 \text{ LSB}$.

NEGATIVE GAIN ERROR is the difference between the negative full-scale error and the offset error.

OFFSET ERROR is the difference between the differential input voltage at which the output code transitions from code 0x0000h to 0x0001h and 1 LSB.

POSITIVE FULL-SCALE ERROR is the difference between the differential input voltage at which the output code transitions from code 0xFFFEh to 0xFFFFh and $V_{\text{REF}} - 1 \text{ LSB}$.

POSITIVE GAIN ERROR is the difference between the positive full-scale error and the offset error.

POWER SUPPLY REJECTION RATIO (PSRR) is a measure of how well a change in the analog supply voltage is rejected. PSRR is calculated from the ratio of the change in offset error for a given change in supply voltage, expressed in dB. For the ADC161S626, V_A is changed from 4.5V to 5.5V.

$$\text{PSRR} = 20 \text{ LOG} (\Delta \text{Output Offset} / \Delta V_A)$$

SIGNAL TO NOISE RATIO (SNR) is the ratio, expressed in dB, of the rms value of the input signal to the rms value of the sum of all other spectral components below one-half the sampling frequency, not including harmonics or d.c.

SIGNAL TO NOISE PLUS DISTORTION (S/N+D or SINAD) is the ratio, expressed in dB, of the rms value of the input signal to the rms value of all of the other spectral components below one-half the sampling frequency, including harmonics but excluding d.c.

SPURIOUS FREE DYNAMIC RANGE (SFDR) is the difference, expressed in dB, between the desired signal amplitude to the amplitude of the peak spurious spectral component below one-half the sampling frequency, where a spurious spectral component is any signal present in the output spectrum that is not present at the input and may or may not be a harmonic.

TOTAL HARMONIC DISTORTION (THD) is the ratio of the rms total of the first five harmonic components at the output to the rms level of the input signal frequency as seen at the output, expressed in dB. THD is calculated as

$$\text{THD} = 20 \times \log_{10} \sqrt{\frac{A_{f2}^2 + \dots + A_{f6}^2}{A_{f1}^2}}$$

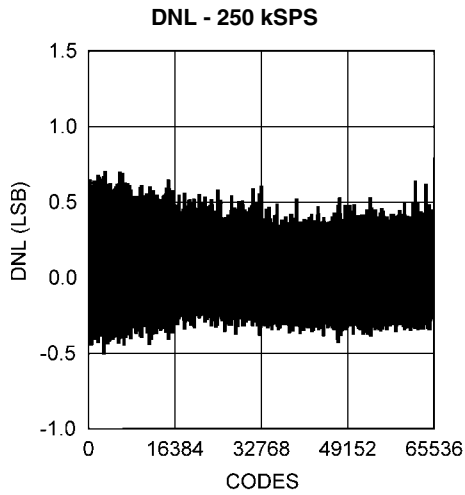
where A_{f1} is the RMS power of the input frequency at the output and A_{f2} through A_{f6} are the RMS power in the first 5 harmonic frequencies.

THROUGHPUT TIME is the minimum time required between the start of two successive conversion.

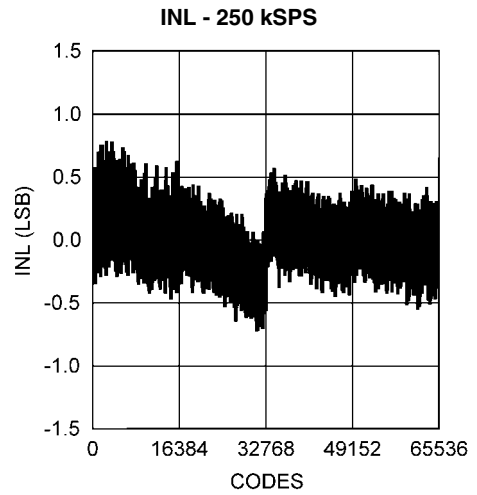
Typical Performance Characteristics

+25°C, and $f_{IN} = 20$ kHz unless otherwise stated.

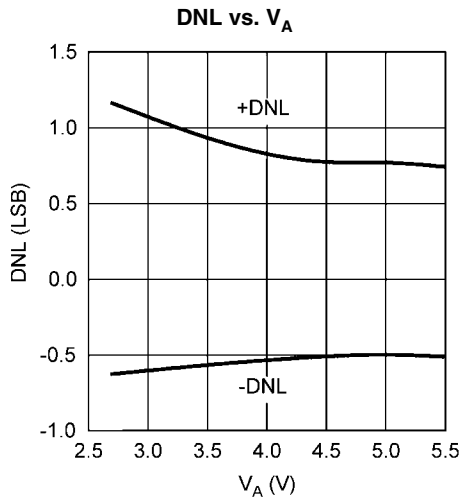
$V_A = V_{IO} = V_{REF} = +5V$, $f_{SCLK} = 5$ MHz, $f_{SAMPLE} = 250$ kSPS, $T_A =$



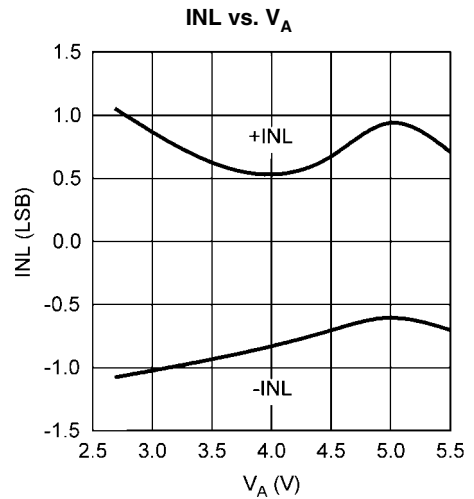
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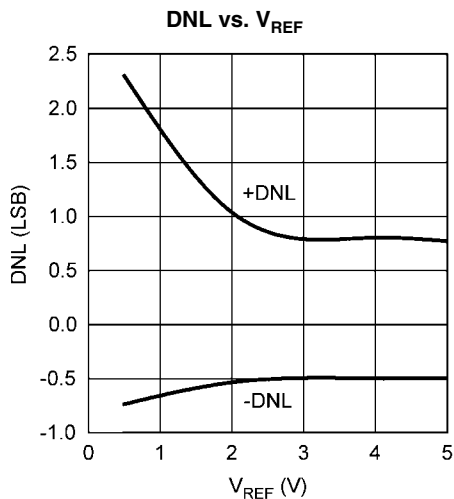
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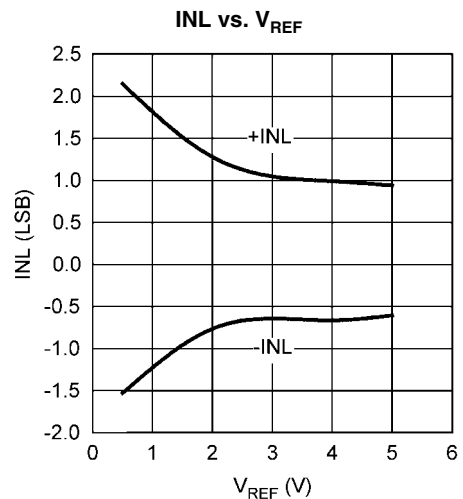
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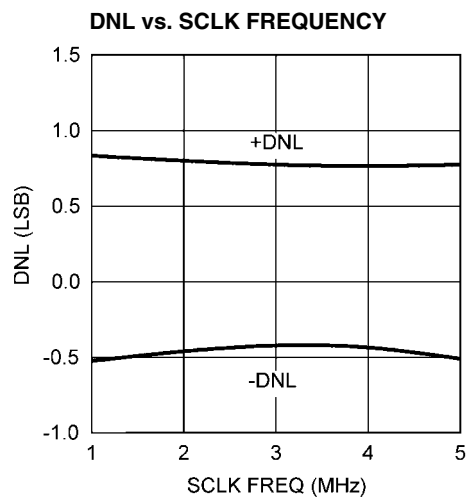
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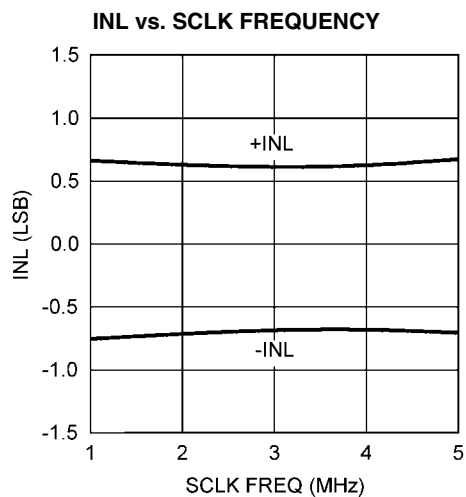
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Typical Performance Characteristics

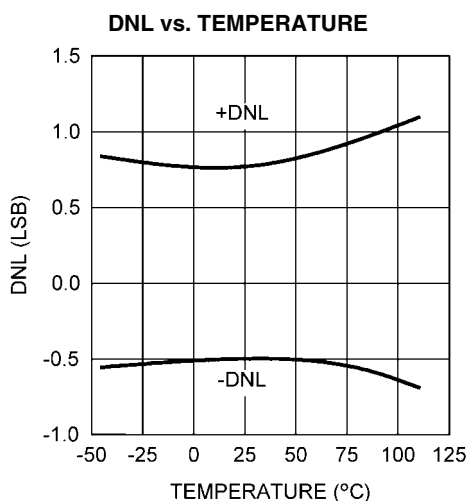
$V_A = V_{IO} = V_{REF} = +5V$, $f_{SCLK} = 5\text{ MHz}$, $f_{SAMPLE} = 250\text{ kSPS}$, $T_A = +25^\circ\text{C}$, and $f_{IN} = 20\text{ kHz}$ unless otherwise stated.



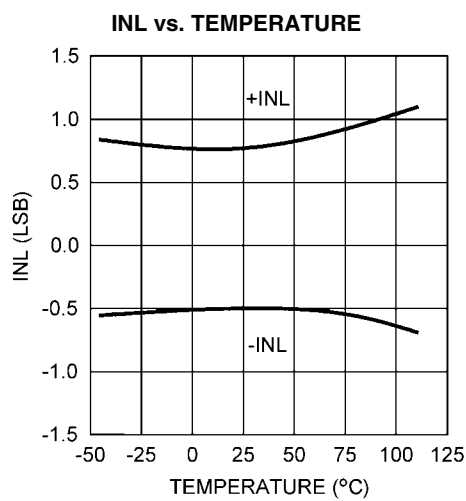
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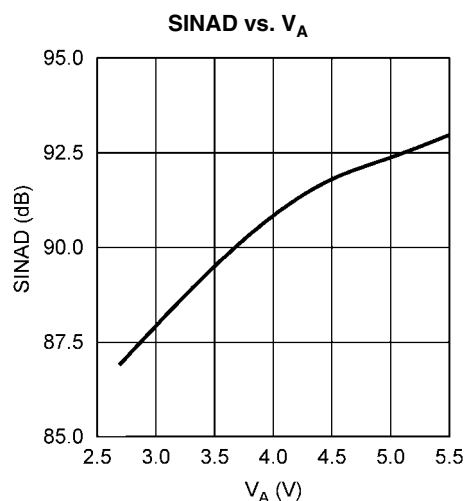
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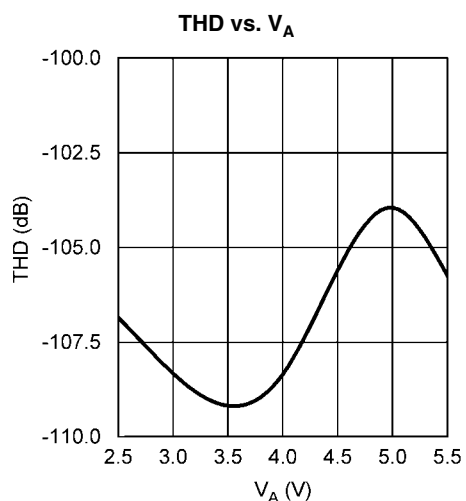
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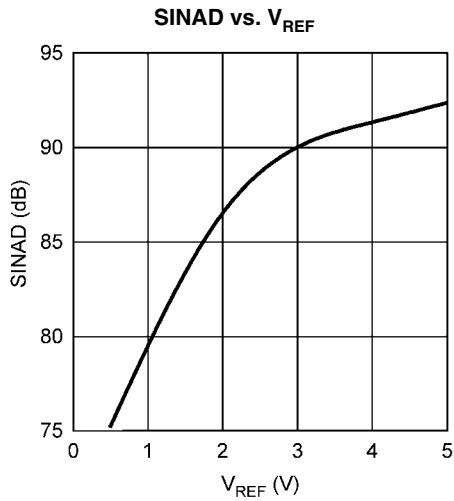
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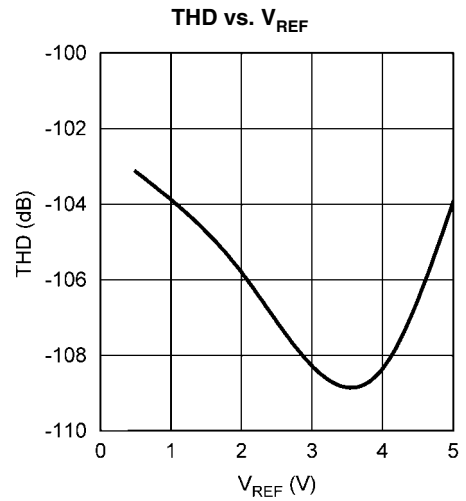
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Typical Performance Characteristics

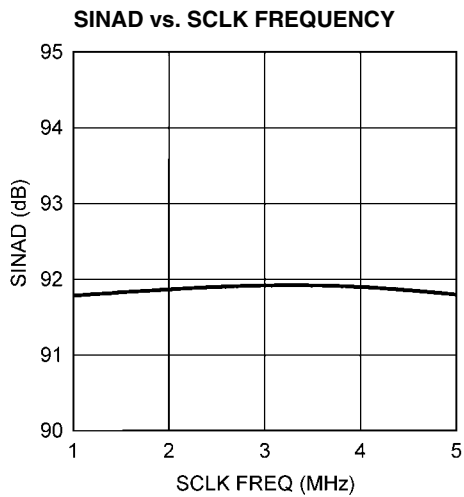
$V_A = V_{IO} = V_{REF} = +5V$, $f_{SCLK} = 5\text{ MHz}$, $f_{SAMPLE} = 250\text{ kSPS}$, $T_A = +25^\circ\text{C}$, and $f_{IN} = 20\text{ kHz}$ unless otherwise stated.



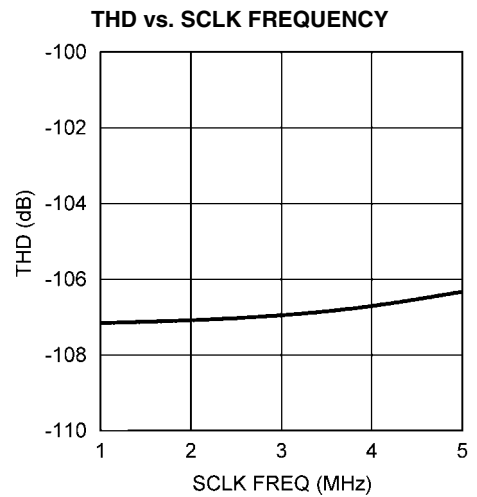
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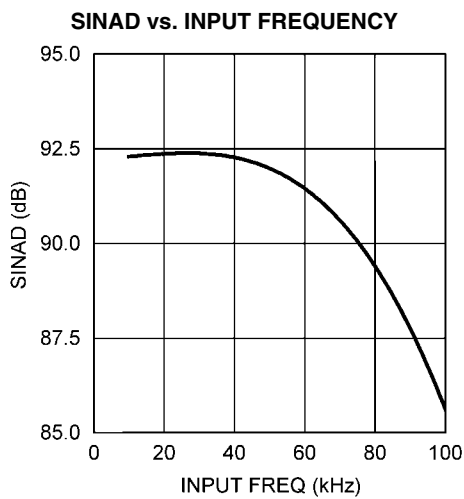
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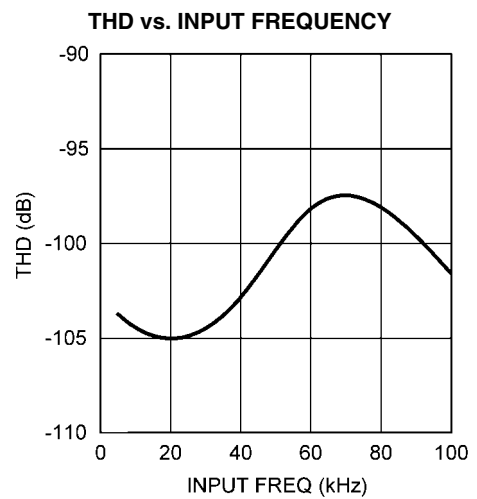
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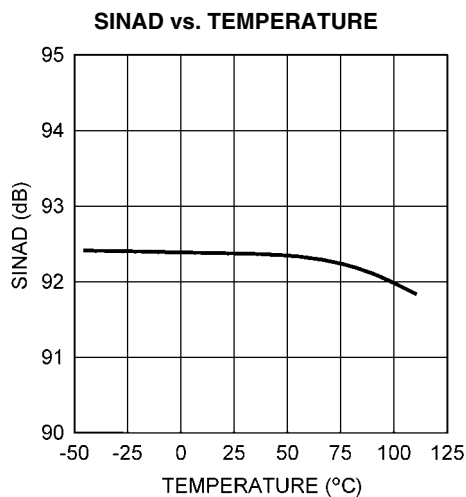
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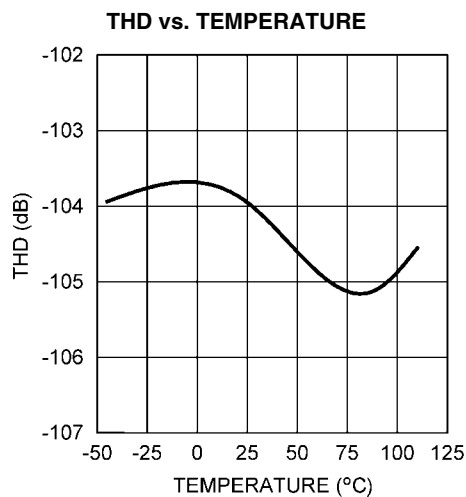
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Typical Performance Characteristics

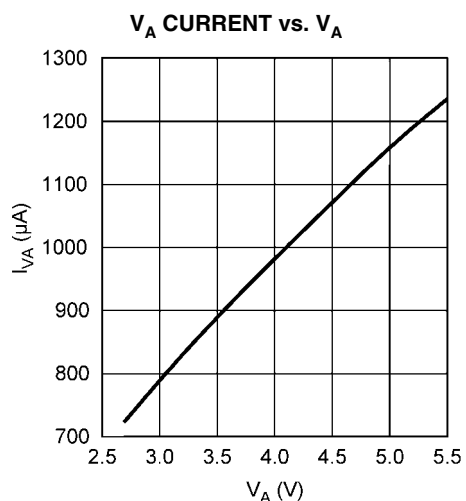
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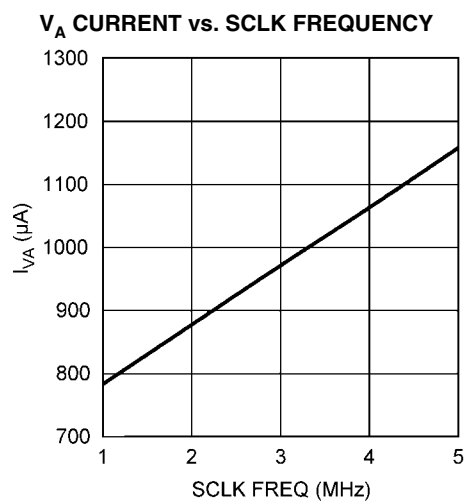
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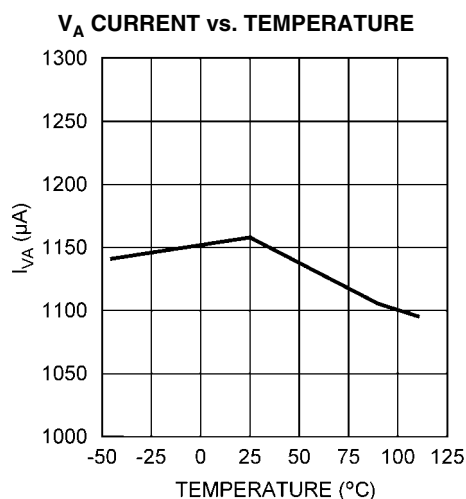
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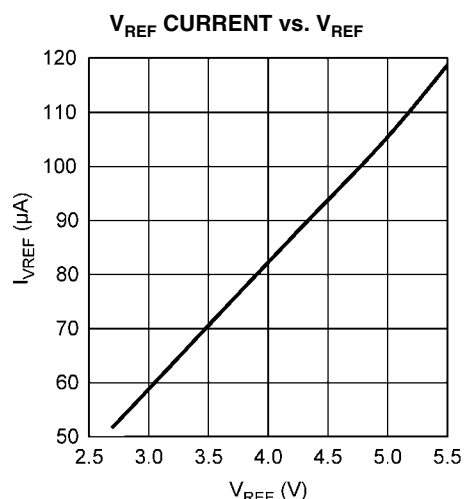
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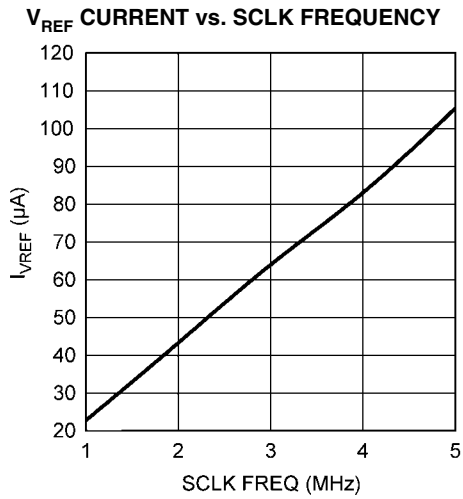
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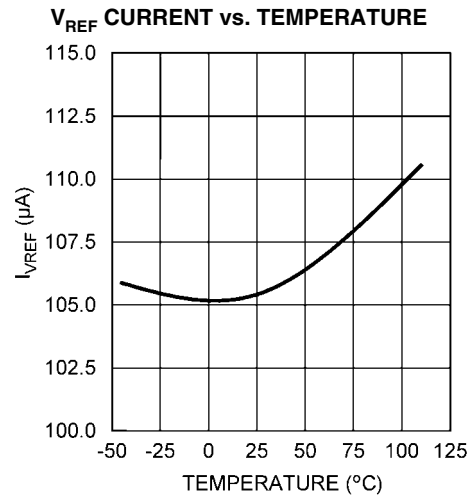
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Typical Performance Characteristics

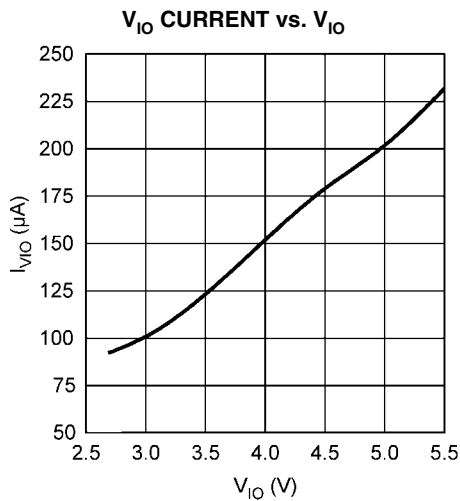
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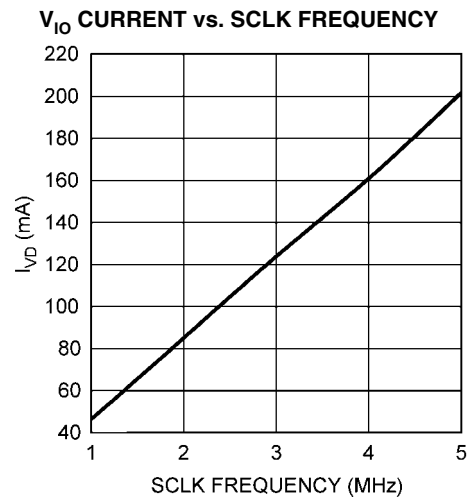
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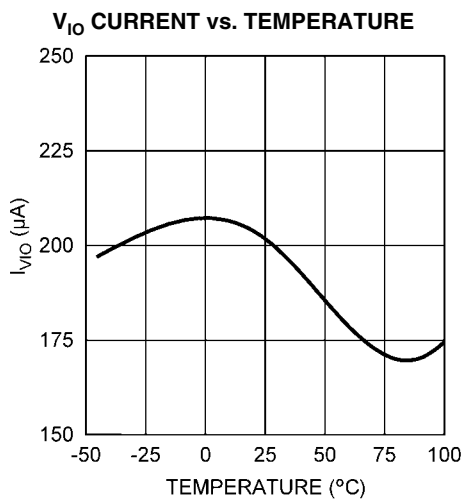
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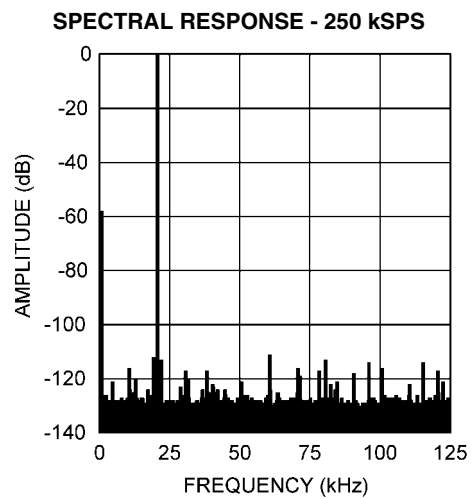
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Functional Description

The ADC161S626 is a 16-bit, 50 kSPS to 250 kSPS sampling Analog-to-Digital (A/D) converter. The converter uses a successive approximation register (SAR) architecture based upon capacitive redistribution containing an inherent sample-and-hold function. The differential nature of the analog inputs is maintained from the internal sample-and-hold circuits throughout the A/D converter to provide excellent common-mode signal rejection.

The ADC161S626 operates from independent analog and digital supplies. The analog supply (V_A) can range from 4.5V to 5.5V and the digital input/output supply (V_{IO}) can range from 2.7V to 5.5V. The ADC161S626 utilizes an external reference (V_{REF}), which can be any voltage between 0.5V and V_A . The value of V_{REF} determines the range of the analog input, while the reference input current (I_{REF}) depends upon the conversion rate.

The analog input is presented to two input pins: +IN and -IN. Upon initiation of a conversion, the differential input at these pins is sampled on the internal capacitor array. The inputs are disconnected from the internal circuitry while a conversion is in progress. The ADC161S626 features a zero-power track mode (ZPTM) where the ADC is consuming the minimum amount of power (Power-Down Mode) while the internal sampling capacitor array is tracking the applied analog input voltage. The converter enters ZPTM at the end of each conversion window and experiences no delay when the ADC enters into Conversion Mode. This feature allows the user an easy means for optimizing system performance based on the settling capability of the analog source while minimizing power consumption. ZPTM is exercised by bringing chip select bar (\overline{CS}) high or when \overline{CS} is held low after the conversion is complete (after the 18th falling edge of the serial clock).

The ADC161S626 communicates with other devices via a Serial Peripheral Interface (SPI™), a synchronous serial interface that operates using three pins: chip select bar (\overline{CS}), serial clock (SCLK), and serial data out (D_{OUT}). The external SCLK controls data transfer and serves as the conversion clock. The duty cycle of SCLK is essentially unimportant, provided the minimum clock high and low times are met. The minimum SCLK frequency is set by internal capacitor leakage. Each conversion requires a minimum of 18 SCLK cycles to complete. If less than 16 bits of conversion data are required, \overline{CS} can be brought high at any point during the conversion. This procedure of terminating a conversion prior to completion is commonly referred to as short cycling.

The digital conversion result is clocked out by the SCLK input and is provided serially, most significant bit (MSB) first, at the D_{OUT} pin. The digital data that is provided at the D_{OUT} pin is that of the conversion currently in progress and thus there is no pipe line delay or latency.

1.0 REFERENCE INPUT (V_{REF})

The externally supplied reference voltage (V_{REF}) sets the analog input range. The ADC161S626 will operate with V_{REF} in the range of 0.5V to V_A .

Operation with V_{REF} below 2.5V is possible with slightly diminished performance. As V_{REF} is reduced, the range of acceptable analog input voltages is reduced. Assuming a proper common-mode input voltage (V_{CM}), the differential

peak-to-peak input range is limited to $(2 \times V_{REF})$. See Section 2.3 for more details.

Reducing V_{REF} also reduces the size of the least significant bit (LSB). For example, the size of one LSB is equal to $[(2 \times V_{REF}) / 2^n]$, which is 152.6 μ V where n is 16 bits and V_{REF} is 5V. When the LSB size goes below the noise floor of the ADC161S626, the noise will span an increasing number of codes and overall performance will suffer. Dynamic signals will have their SNR degrade; while, D.C. measurements will have their code uncertainty increase. Since the noise is Gaussian in nature, the effects of this noise can be reduced by averaging the results of a number of consecutive conversions.

V_{REF} and analog inputs (+IN and -IN) are connected to the capacitor array through a switch matrix when the input is sampled. Hence, I_{REF} , I_{+IN} , and I_{-IN} are a series of transient spikes that occur at a frequency dependent on the operating sample rate of the ADC161S626.

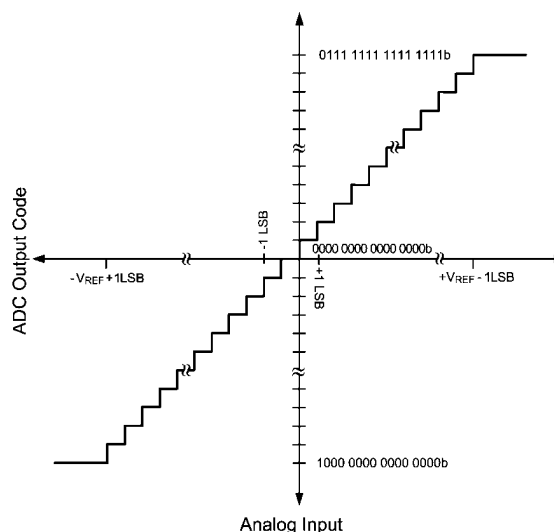
I_{REF} changes only slightly with temperature. See the curves, "Reference Current vs. SCLK Frequency" and "Reference Current vs. Temperature" in the Typical Performance Curves section for additional details.

2.0 ANALOG SIGNAL INPUTS

The ADC161S626 has a differential input where the effective input voltage that is digitized is (+IN) – (–IN).

2.1 Differential Input Operation

The transfer curve of the ADC161S626 for a fully differential input signal is shown in Figure 7. A positive full scale output code (0111 1111 1111 1111b or 7FFFh or 32,767d) will be obtained when (+IN) – (–IN) is greater than or equal to $(V_{REF} - 1 \text{ LSB})$. A negative full scale code (1000 0000 0000 0000b or 8000h or -32,768d) will be obtained when [(+IN) – (–IN)] is less than or equal to $(-V_{REF} + 1 \text{ LSB})$. This ignores gain, offset and linearity errors, which will affect the exact differential input voltage that will determine any given output code.



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FIGURE 7. ADC Transfer Curve

Both inputs should be biased at a common mode voltage (V_{CM}), which will be thoroughly discussed in Section 2.3. *Figure 8* shows the ADC161S626 being driven by a full-scale differential source.

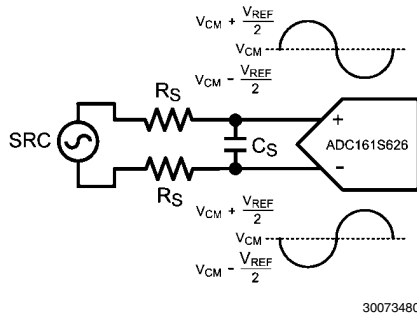


FIGURE 8. Differential Input

2.2 Single-Ended Input Operation

For single-ended operation, the non-inverting input (+IN) of the ADC161S626 can be driven with a signal that has a peak-to-peak range that is equal to or less than ($2 \times V_{REF}$). The inverting input (-IN) should be biased at a stable V_{CM} that is halfway between these maximum and minimum values. In order to utilize the entire dynamic range of the ADC161S626, V_{REF} is limited to ($V_A / 2$). This allows +IN a maximum swing range of ground to V_A . *Figure 9* shows the ADC161S626 being driven by a full-scale single-ended source.

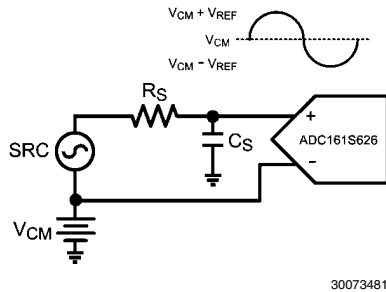


FIGURE 9. Single-Ended Input

Since the design of the ADC161S626 is optimized for a differential input, the performance degrades slightly when driven with a single-ended input. Linearity characteristics such as INL and DNL typically degrade by 0.1 LSB and dynamic characteristics such as SINAD typically degrade by 2 dB. Note that single-ended operation should only be used if the performance degradation (compared with differential operation) is acceptable.

2.3 Input Common Mode Voltage

The allowable input common mode voltage (V_{CM}) range depends upon V_A and V_{REF} used for the ADC161S626. The ranges of V_{CM} are depicted in *Figure 10* and *Figure 11*. Note that these figures only apply to a V_A of 5V. Equations for calculating the minimum and maximum V_{CM} for differential and single-ended operations are shown in *Table 1*.

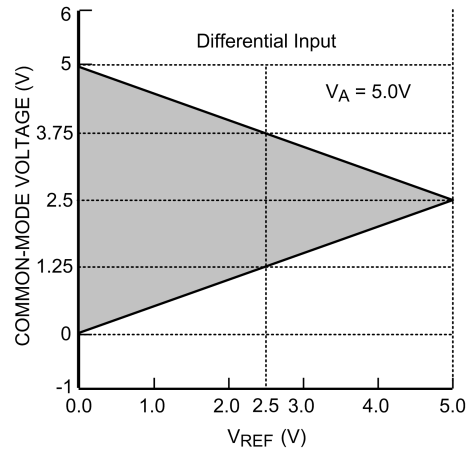


FIGURE 10. V_{CM} range for Differential Input operation

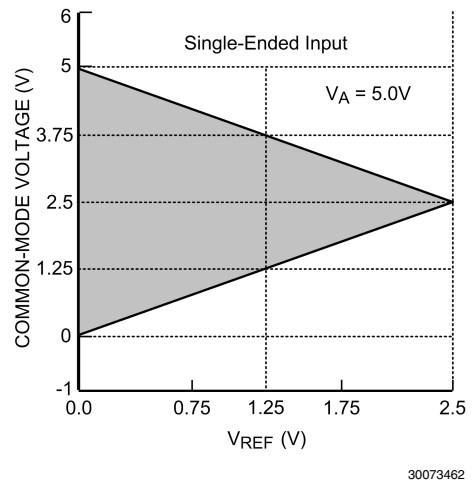


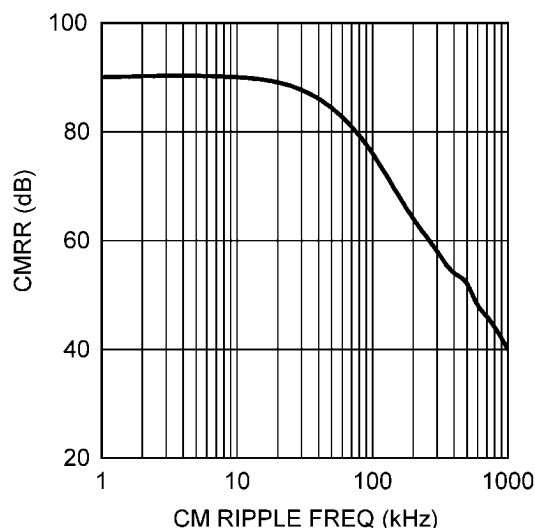
FIGURE 11. V_{CM} range for single-ended operation

TABLE 1. Allowable V_{CM} Range

Input Signal	Minimum V_{CM}	Maximum V_{CM}
Differential	$V_{REF} / 2$	$V_A - V_{REF} / 2$
Single-Ended	V_{REF}	$V_A - V_{REF}$

2.4 CMRR

By using this differential input, small signals common to both inputs are rejected. As shown in *Figure 12*, noise is immune at low frequencies where the common-mode rejection ratio (CMRR) is 90 dB. As the frequency increases to 1 MHz, the CMRR rolls off to 40 dB. In general, operation with a fully differential input signal or voltage will provide better performance than with a single-ended input. However, if desired, the ADC161S626 can be presented with a single-ended input.



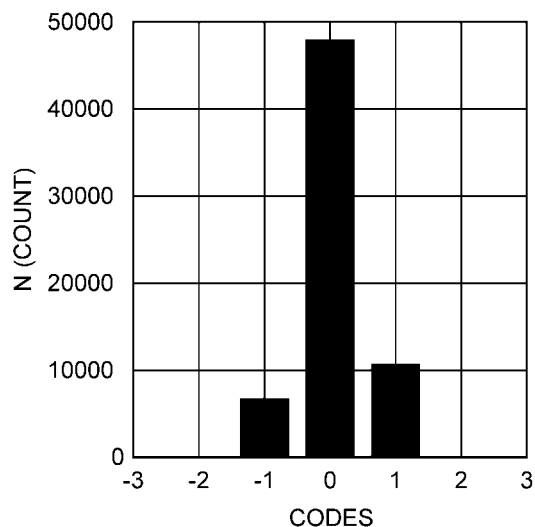
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FIGURE 12. Analog Input CMRR vs. Frequency

2.5 Noise

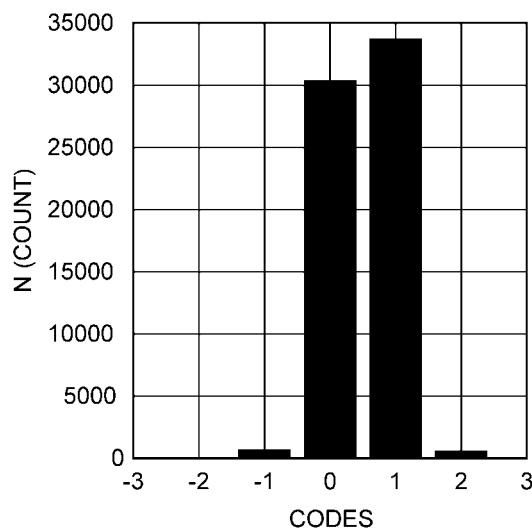
The noise floor of the ADC161S626 is very low as shown in Figure 13 and Figure 14. These figures were created by driving the ADC input with a low-noise voltage source set near 0V. For Figure 13, the input was adjusted in order to obtain the code 0x0000h. For Figure 14, the input was increased by 1/2 LSB in order to obtain the transition point between code 0x0000h and 0x0001h. In both instances, 2^{16} (65,534) samples were collected and plotted in a histogram format.

Ideally the noise histogram at code center would show a single output code while the noise histogram at code transition would show two output codes. Any codes outside of the ideal output are a result of the internal noise of the ADC161S626 and the input source. Since the ADC161S626 has very low internal noise, only two codes outside of the center code are exhibited in the histogram of Figure 13. Similar results are shown in Figure 14.



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FIGURE 13. Noise Histogram at Code Center

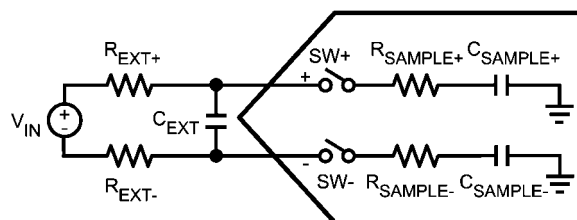


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FIGURE 14. Noise Histogram at Code Transition

2.6 Input Settling

When the ADC161S626 enters acquisition (t_{ACQ}) mode at the end of the conversion window, the internal sampling capacitor (C_{SAMPLE}) is connected to the ADC input via an internal switch and a series resistor (R_{SAMPLE}), as shown in Figure 15. Typical values for C_{SAMPLE} and R_{SAMPLE} are 20 pF and 200 ohms respectively. If there is not a large external capacitor (C_{EXT}) at the analog input of the ADC, a voltage spike will be observed at the input pins. This is a result of C_{SAMPLE} and C_{EXT} being at different voltage potentials. The magnitude and direction of the voltage spike depend on the difference between the voltage of C_{SAMPLE} and C_{EXT} . If the voltage at C_{SAMPLE} is greater than the voltage at C_{EXT} , a positive voltage spike will occur. If the opposite is true, a negative voltage spike will occur. It is not critical for the performance of the ADC161S626 to filter out the voltage spike. Rather, ensure that the transient of the spike settles out within t_{ACQ} ; for recommended solutions, see Section 4.0 in the Application Information.



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FIGURE 15. ADC Input Capacitors

3.0 SERIAL DIGITAL INTERFACE

The ADC161S626 communicates via a synchronous 3-wire serial interface as shown in Figure 1 or re-shown in Figure 16 for convenience. \overline{CS} , chip select bar, initiates conversions and frames the serial data transfers. SCLK (serial clock) controls both the conversion process and the timing of the serial data. D_{OUT} is the serial data output pin, where a conversion result is sent as a serial data stream, MSB first.

A serial frame is initiated on the falling edge of \overline{CS} and ends on the rising edge of \overline{CS} . The ADC161S626's D_{OUT} pin is in a high impedance state when \overline{CS} is high and for the first clock period after \overline{CS} is asserted; D_{OUT} is active for the remainder of time when \overline{CS} is asserted.

The ADC161S626 samples the differential input upon the assertion of \overline{CS} . Assertion is defined as bringing the \overline{CS} pin to a logic low state. For the first 17 periods of the SCLK following the assertion of \overline{CS} , the ADC161S626 is converting the analog input voltage. On the 18th falling edge of SCLK, the ADC161S626 enters acquisition (t_{ACQ}) mode. For the next three periods of SCLK, the ADC161S626 is operating in acquisition mode where the ADC input is tracking the analog input signal applied across +IN and -IN. During acquisition mode, the ADC161S626 is consuming a minimal amount of power.

The ADC161S626 can enter conversion mode (t_{CONV}) under three different conditions. The first condition involves \overline{CS} going low (asserted) with SCLK high. In this case, the ADC161S626 enters conversion mode on the first falling edge of SCLK after \overline{CS} is asserted. In the second condition, \overline{CS} goes low with SCLK low. Under this condition, the ADC161S626 automatically enters conversion mode and the falling edge of \overline{CS} is seen as the first falling edge of SCLK. In the third condition, \overline{CS} and SCLK go low simultaneously and the ADC161S626 enters conversion mode. While there is no timing restriction with respect to the falling edges of \overline{CS} and SCLK, there are minimum setup and hold time requirements for the falling edge of \overline{CS} with respect to the rising edge of SCLK. See Figure 5 in the Timing Diagram section for more information.

3.1 \overline{CS} Input

The \overline{CS} (chip select bar) input is active low and is CMOS compatible. The ADC161S626 enters conversion mode when \overline{CS} is asserted and the SCLK pin is in a logic low state. When \overline{CS} is high, the ADC161S626 is always in acquisition mode and thus consuming the minimum amount of power. Since \overline{CS} must be asserted to begin a conversion, the sample rate of the ADC161S626 is equal to the assertion rate of \overline{CS} .

Proper operation requires that the fall of \overline{CS} not occur simultaneously with a rising edge of SCLK. If the fall of \overline{CS} occurs during the rising edge of SCLK, the data might be clocked out one bit early. Whether or not the data is clocked out early depends upon how close the \overline{CS} transition is to the SCLK transition, the device temperature, and the characteristics of the individual device. To ensure that the MSB is always clocked out at a given time (the 3rd falling edge of SCLK), it is essential that the fall of \overline{CS} always meet the timing requirement specified in the Timing Specification table.

3.2 SCLK Input

The SCLK (serial clock) is used as the conversion clock to shift out the conversion result. SCLK is CMOS compatible. Internal settling time requirements limit the maximum clock frequency while internal capacitor leakage limits the minimum clock frequency. The ADC161S626 offers guaranteed performance with the clock rates indicated in the electrical table.

The ADC161S626 enters acquisition mode on the 18th falling edge of SCLK during a conversion frame. Assuming that the LSB is clocked into a controller on the 18th rising edge of SCLK, there is a minimum acquisition time period that must be met before a new conversion frame can begin. Other than the 18th rising edge of SCLK that was used to latch the LSB into a controller, there is no requirement for the SCLK to transition during acquisition mode. Therefore, it is acceptable to idle SCLK after the LSB has been latched into the controller.

3.3 Data Output

The data output format of the ADC161S626 is two's complement as shown in Figure 7. This figure indicates the ideal output code for a given input voltage and does not include the effects of offset, gain error, linearity errors, or noise. Each data output bit is output on the falling edges of SCLK. D_{OUT} is in a high impedance state for the 1st falling edge of SCLK while the 2nd SCLK falling edge clocks out a leading zero. The 3rd to 18th SCLK falling edges clock out the conversion result, MSB first.

While most receiving systems will capture the digital output bits on the rising edges of SCLK, the falling edges of SCLK may be used to capture the conversion result if the minimum hold time for D_{OUT} is acceptable. See Figure 4 for D_{OUT} hold (t_{DH}) and access (t_{DA}) times.

D_{OUT} is enabled on the second falling edge of SCLK after the assertion of \overline{CS} and is disabled on the rising edge of \overline{CS} . If \overline{CS} is raised prior to the 18th falling edge of SCLK, the current conversion is aborted and D_{OUT} will go into its high impedance state. A new conversion will begin when \overline{CS} is driven LOW.

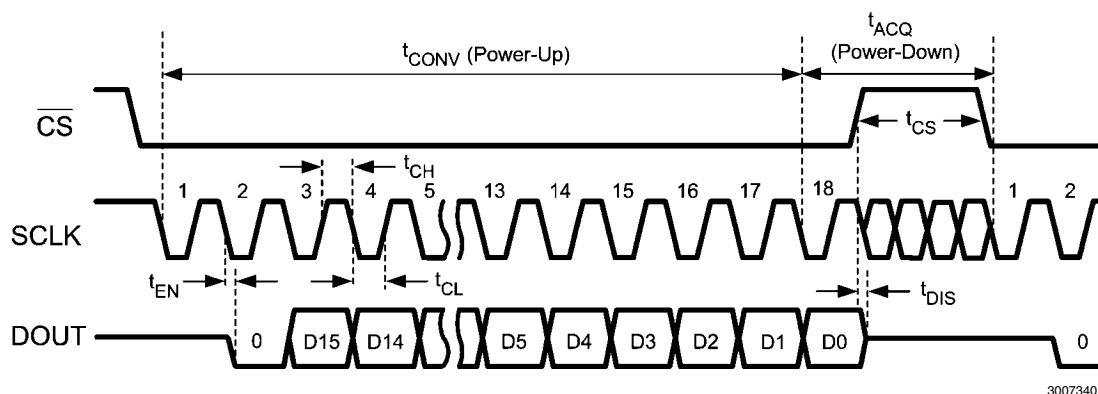


FIGURE 16. ADC161S626 Single Conversion Timing Diagram

Applications Information

OPERATING CONDITIONS

We recommend that the following conditions be observed for operation of the ADC161S626:

- $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$
- $+4.5\text{V} \leq V_A \leq +5.5\text{V}$
- $+2.7\text{V} \leq V_{IO} \leq +5.5\text{V}$
- $+0.5\text{V} \leq V_{REF} \leq +5.5\text{V}$
- $1\text{ MHz} \leq f_{SCLK} \leq 5\text{ MHz}$
- V_{CM} : See Section 2.3

4.0 ANALOG INPUT CONSIDERATIONS

As stated previously in Section 2.6, it is not critical for the performance of the ADC161S626 to filter out the voltage spike that occurs when the ADC161S626 enters acquisition (t_{ACQ}) mode at the end of the conversion window. However, it is critical that a system designer ensures that the transients of the spike settle out within t_{ACQ} . The burden of this task can be placed on the analog source itself or the burden can be shared by the source and an external capacitor, C_{EXT} as shown in Figure 15. The external capacitor acts as a local charge reservoir for the internal sampling capacitor and thus reduces the size of the voltage spike. For low frequency analog sources such as sensors with DC-like output behaviors, C_{EXT} values greater than 1 nF are recommended. However, some sensors and signal conditioning circuitry will not be able to maintain their stability in the presence of the external capacitive load. In these instances, a series resistor (R_{EXT}) is recommended. The magnitude of R_{EXT} is dependent on the output capability of the analog source and the settling requirement of the ADC. Independent of the presence of an external capacitor, the system designer always has the option of lowering the sample rate of the ADC161S626 which directly controls the amount of time allowed for the voltage spike to settle. The slower the sample rate, the longer the t_{ACQ} time or settling time. This is possible with the ADC161S626 since the converter enters t_{ACQ} at the end of the prior conversion and thus is tracking the analog input source the entire time between conversions.

5.0 POWER CONSUMPTION

The architecture, design, and fabrication process allow the ADC161S626 to operate at conversion rates up to 250 kSPS while consuming very little power. The ADC161S626 consumes the least amount of power while operating in acquisition (power-down) mode. For applications where power consumption is critical, the ADC161S626 should be operated in acquisition mode as often as the application will tolerate. To further reduce power consumption, stop the SCLK while \overline{CS} is high.

5.1 Short Cycling

Short cycling refers to the process of halting a conversion after the last needed bit is outputted. Short cycling can be used to lower the power consumption in those applications that do not need a full 16-bit resolution, or where an analog signal is being monitored until some condition occurs. In some circumstances, the conversion could be terminated after the first few bits. This will lower power consumption in the converter since the ADC161S626 spends more time in acquisition mode and less time in conversion mode.

Short cycling is accomplished by pulling \overline{CS} high after the last required bit is received from the ADC161S626 output. This is possible because the ADC161S626 places the latest converted data bit on D_{OUT} as it is generated. If only 10-bits of the

conversion result are needed, for example, the conversion can be terminated by pulling \overline{CS} high after the 10th bit has been clocked out.

5.2 Burst Mode Operation

Normal operation of the ADC161S626 requires the SCLK frequency to be 20 times the sample rate and the \overline{CS} rate to be the same as the sample rate. However, in order to minimize power consumption in applications requiring sample rates below 250 kSPS, the ADC161S626 should be run with an SCLK frequency of 5 MHz and a \overline{CS} rate as slow as the system requires. When this is accomplished, the ADC161S626 is operating in burst mode. The ADC161S626 enters into acquisition mode at the end of each conversion, minimizing power consumption. This causes the converter to spend the longest possible time in acquisition mode. Since power consumption scales directly with conversion rate, minimizing power consumption requires determining the lowest conversion rate that will satisfy the requirements of the system.

6.0 PCB LAYOUT AND CIRCUIT CONSIDERATIONS

For best performance, care should be taken with the physical layout of the printed circuit board. This is especially true with a low V_{REF} or when the conversion rate is high. At high clock rates there is less time for settling, so it is important that any noise settles out before the conversion begins.

6.1 Analog and Digital Power Supplies

Any ADC architecture is sensitive to spikes on the power supply, reference, and ground pins. These spikes may originate from switching power supplies, digital logic, high power devices, and other sources. Power to the ADC161S626 should be clean and well bypassed. A 0.1 μF ceramic bypass capacitor and a 1 μF to 10 μF capacitor should be used to bypass the ADC161S626 supply, with the 0.1 μF capacitor placed as close to the ADC161S626 package as possible.

Since the ADC161S626 has both the V_A and V_{IO} pins, the user has three options on how to connect these pins. The first option is to tie V_A and V_{IO} together and power them with the same power supply. This is the most cost effective way of powering the ADC161S626 but is also the least ideal. As stated previously, noise from V_{IO} can couple into V_A and adversely affect performance. The other two options involve the user powering V_A and V_{IO} with separate supply voltages. These supply voltages can have the same amplitude or they can be different. V_A can be set to any value between +4.5V and +5.5V; while V_{IO} can be set to any value between +2.7V and +5.5V.

Best performance will typically be achieved with V_A operating at 5V and V_{IO} at 3V. Operating V_A at 5V offers the best linearity and dynamic performance when V_{REF} is also set to 5V; while operating V_{IO} at 3V reduces the power consumption of the digital logic. Operating the digital interface at 3V also has the added benefit of decreasing the noise created by charging and discharging the capacitance of the digital interface pins.

6.2 Voltage Reference

The reference source must have a low output impedance and needs to be bypassed with a minimum capacitor value of 0.1 μF . A larger capacitor value of 1 μF to 10 μF placed in parallel with the 0.1 μF is preferred. While the ADC161S626 draws very little current from the reference on average, there are higher instantaneous current spikes at the reference.

V_{REF} of the ADC161S626, like all A/D converters, does not reject noise or voltage variations. Keep this in mind if V_{REF} is derived from the power supply. Any noise and/or ripple from the supply that is not rejected by the external reference circuitry will appear in the digital results. The use of an active

reference source is recommended. The LM4040 and LM4050 shunt reference families and the LM4120 and LM4140 series reference families are excellent choices for a reference source.

6.3 PCB Layout

Capacitive coupling between the noisy digital circuitry and the sensitive analog circuitry can lead to poor performance. The solution is to keep the analog circuitry separated from the digital circuitry and the clock line as short as possible. Digital circuits create substantial supply and ground current transients. The logic noise generated could have significant impact upon system noise performance. To avoid performance degradation of the ADC161S626 due to supply noise, avoid using the same supply for the V_A and V_{REF} of the ADC161S626 that is used for digital circuitry on the board.

Generally, analog and digital lines should cross each other at 90° to avoid crosstalk. However, to maximize accuracy in high resolution systems, avoid crossing analog and digital lines altogether. It is important to keep clock lines as short as possible and isolated from ALL other lines, including other digital lines. In addition, the clock line should also be treated as a transmission line and be properly terminated. The analog input should be isolated from noisy signal traces to avoid coupling of spurious signals into the input. Any external component (e.g., a filter capacitor) connected between the converter's input pins and ground or to the reference input pin and ground should be connected to a very clean point in the ground plane.

A single, uniform ground plane and the use of split power planes are recommended. The power planes should be lo-

cated within the same board layer. All analog circuitry (input amplifiers, filters, reference components, etc.) should be placed over the analog power plane. All digital circuitry should be placed over the digital power plane. Furthermore, the GND pins on the ADC161S626 and all the components in the reference circuitry and input signal chain that are connected to ground should be connected to the ground plane at a quiet point. Avoid connecting these points too close to the ground point of a microprocessor, microcontroller, digital signal processor, or other high power digital device.

7.0 APPLICATION CIRCUITS

The following figures are examples of the ADC161S626 in typical application circuits. These circuits are basic and will generally require modification for specific circumstances.

7.1 Data Acquisition

Figure 17 shows a typical connection diagram for the ADC161S626 operating at V_A of +5V. V_{REF} is connected to a 2.5V shunt reference, the LM4020-2.5, to define the analog input range of the ADC161S626 independent of supply variation on the +5V supply line. The V_{REF} pin should be de-coupled to the ground plane by a 0.1 μ F ceramic capacitor and a tantalum capacitor of 10 μ F. It is important that the 0.1 μ F capacitor be placed as close as possible to the V_{REF} pin while the placement of the tantalum capacitor is less critical. It is also recommended that the V_A and V_{IO} pins of the ADC161S626 be de-coupled to ground by a 0.1 μ F ceramic capacitor in parallel with a 10 μ F tantalum capacitor.

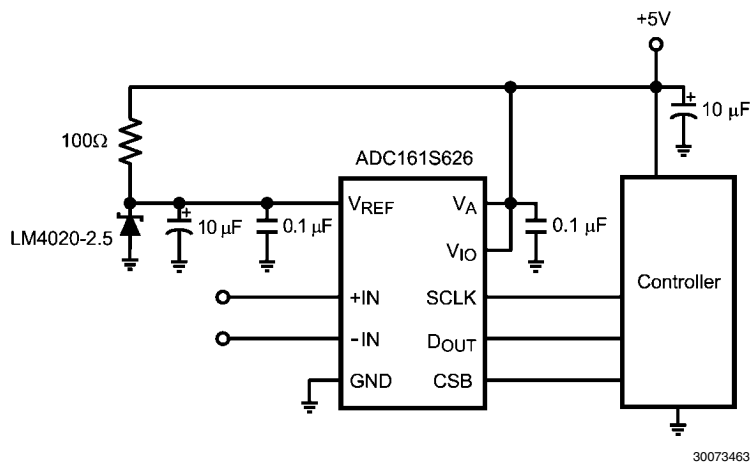


FIGURE 17. Low cost, low power Data Acquisition System

7.2 Bridge Sensor Application

Figure 18 and Figure 19 show examples of interfacing bridge sensors to the ADC161S626. The applications assume that the bridge sensors require buffering and amplification to fully utilize the dynamic range of the ADC and thus optimize the performance of the entire signal path. The amplification stages consist of the LMP7732 and the LMP7731, dual and single precision amplifiers, and some gain setting passive components. The amplification stages offer the benefit of high input impedance and high amplification capability.

Figure 19, which has the amplification stage configured as an instrumentation amplifier, has the added benefit of additional common-mode rejection of common-mode noise or DC-volt-

ages coming from the bridge sensor. Depending on the voltage applied at V_{CM} , the ADC161S626 in the single-ended application will convert the output voltage of a bridge sensor that contains both a positive and negative component or a bridge sensor that only outputs a positive voltage. For the case of a sensor with both positive and negative output capability, it is recommended that V_{CM} be connected to V_{REF} . For a sensor that only outputs a positive voltage, V_{CM} would need to be connected to ground. Both of these scenarios will allow all the ADC output codes to be potentially utilized.

A separate power supply (V_{BR}) is assumed to be biasing the bridge sensor but another option for biasing the bridge sensor would be powering it from the +5V power supply. This option has the benefit of providing the ideal common-mode input

voltage for the ADC161S626, while keeping design complexity and cost to a minimum. However, any fluctuation in the +5V supply will still be visible on the differential input to the amplification stage. The LM4120-4.1, a 4.1V series reference, and the LM4120-2.5, a 2.5V series reference, are used as the reference voltages in the respective application drawings. The

application in *Figure 19* is limited to a V_{REF} of 2.5V or less because of the single-ended configuration of the differential ADC161S626, as discussed in Section 2.2. The ADC161S626 and the LM4120's are all powered from the same +5V voltage source.

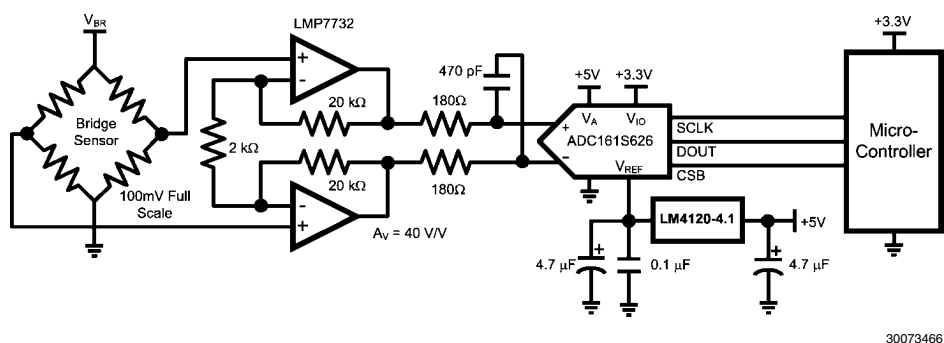


FIGURE 18. Differential Application for a Bridge Sensor

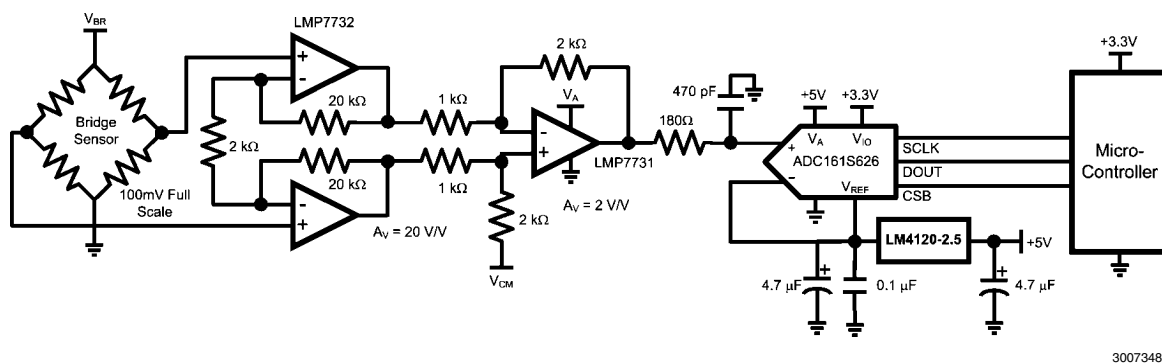
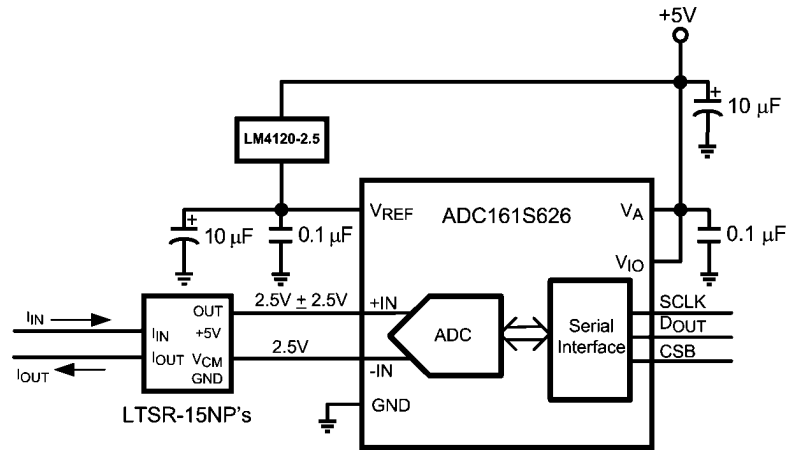


FIGURE 19. Single-Ended Application for a Bridge Sensor

7.3 Current Sensing Application

Figure 20 shows an example of interfacing a current transducer to the ADC161S626. The current transducer converts an input current into a voltage that is converted by the ADC. Since the output voltage of the current transducer is single-ended and centered around a common-mode voltage (V_{CM}) of 2.5V, the ADC161S626 is configured with the output of the transducer driving the non-inverting input and V_{CM} of the transducer driving the inverting input. The output of the trans-

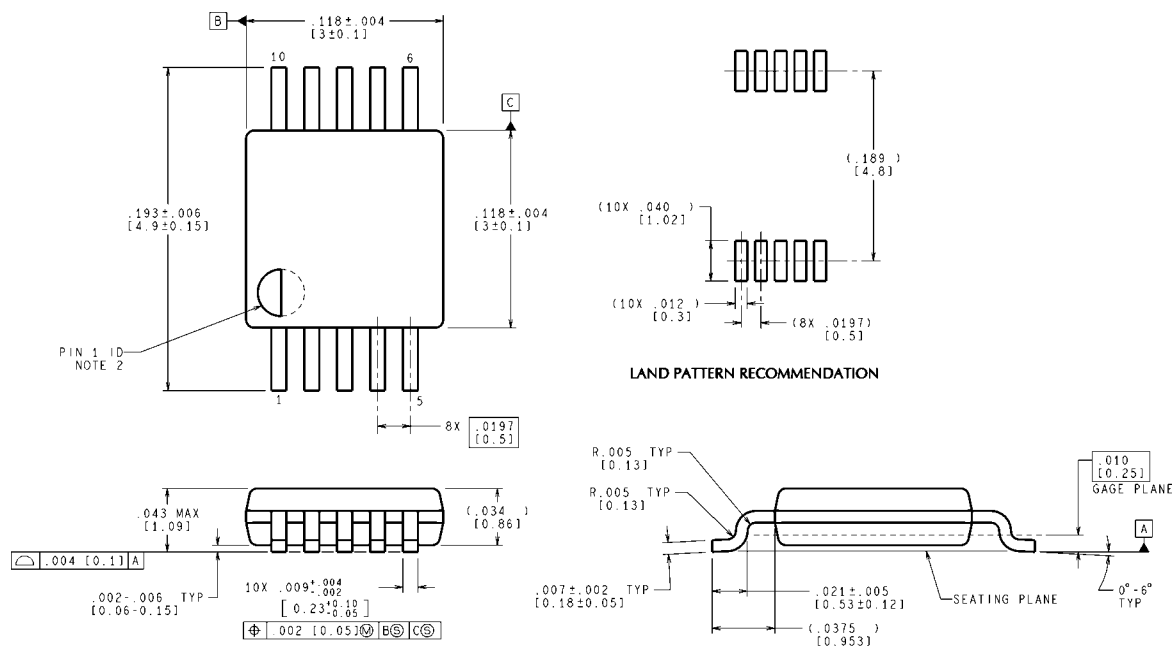
ducer has an output range of $\pm 2.5V$ around V_{CM} of 2.5V. As a result, a series reference voltage of 2.5V is connected to the ADC161S626. This will allow all of the codes of the ADC161S626 to be available for the application. This configuration of the ADC161S626 is referred to as a single-ended application of a differential ADC. All of the elements in the application are conveniently powered by the same +5V power supply, keeping circuit complexity and cost to a minimum.



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FIGURE 20. Interfacing the ADC161S626 to a Current Transducer

Physical Dimensions inches (millimeters) unless otherwise noted



CONTROLLING DIMENSION IS INCH
VALUES IN [] ARE MILLIMETERS
DIMENSIONS IN () FOR REFERENCE ONLY

10-Lead MSOP
Order Number ADC161S626CMM
NS Package Number MUB10A

MUB10A (Rev B)

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Power Management	www.national.com/power	Green Compliance	www.national.com/quality/green
Switching Regulators	www.national.com/switchers	Distributors	www.national.com/contacts
LDOs	www.national.com/ldo	Quality and Reliability	www.national.com/quality
LED Lighting	www.national.com/led	Feedback/Support	www.national.com/feedback
Voltage Reference	www.national.com/vref	Design Made Easy	www.national.com/easy
PowerWise® Solutions	www.national.com/powerwise	Solutions	www.national.com/solutions
Serial Digital Interface (SDI)	www.national.com/sdi	Mil/Aero	www.national.com/milaero
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