



2.7 V to 5.5 V, 600 μ A, Rail-to-Rail Output Quad 12-16-Bit *nanoDAC*[™]

Preliminary Technical Data

AD5624/AD5664

FEATURES

Low power quad *nanoDAC*s

AD5664: 16 Bits

AD5624: 12 Bits

Relative Accuracy: ± 12 LSBs max

10-lead MSOP and 3mmx3mm LFCSP package

2.7 V to 5.5 V power supply

Guaranteed monotonic by design

Power-on reset to zero

Per channel power-down

Serial interface ; Up to 50MHz

APPLICATIONS

Process control

Data acquisition systems

Portable battery-powered instruments

Digital gain and offset adjustment

Programmable voltage and current sources

Programmable attenuators

GENERAL DESCRIPTION

The AD5624/AD5664, members of the *nanoDAC* family are low power, quad, 12-16-bit buffered voltage-out DAC that operates from a single 2.7 V to 5.5 V supply and are guaranteed monotonic by design.

The AD5624/AD5664 requires an external reference voltage to set the output range of the DAC. The part incorporates a power-on reset circuit that ensures the DAC output powers up to 0 V and remains there until a valid write takes place. The part contains a power-down feature that reduces the current consumption of the device to 480 nA at 5 V and provides software-selectable output loads while in power-down mode.

The low power consumption of these parts in normal operation makes them ideally suited to portable battery-operated equipment. The power consumption is 3 mW at 5 V, going down to 2.4 μ W in power-down mode.

The AD5624/AD5664's on-chip precision output amplifier allows rail-to-rail output swing to be achieved.

FUNCTIONAL BLOCK DIAGRAM

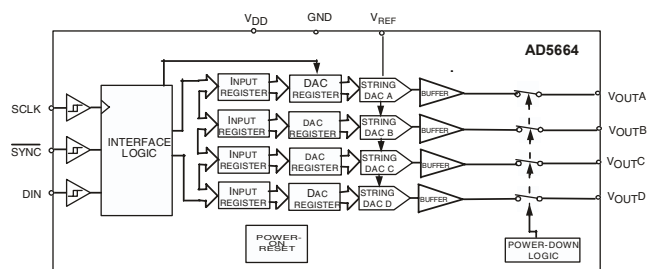


Figure 1.

Table 1. Related Devices

Part No.	Description
AD5624R/AD5644R/AD5664R	2.7V to 5.5V 12-/14-/16-bit DAC with internal reference

The AD5624/AD5664 uses a versatile 3-wire serial interface that operates at clock rates up to 50 MHz, and is compatible with standard SPI[®], QSPI[™], MICROWIRE[™], and DSP interface standards.

PRODUCT HIGHLIGHTS

1. Relative Accuracy: ± 12 LSBs max
2. Available in 10-lead MSOP and 10-lead 3mmx3mm LFCSP package.
3. Low power. Typically consumes 1.5 mW at 3 V and 3 mW at 5 V.
4. 10 μ s max settling time.

Rev. PrB

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REVISION HISTORY

2/06—Revision 0: Initial Version

SPECIFICATIONS

$V_{DD} = +2.7\text{ V to }+5.5\text{ V}$; $R_L = 2\text{ k}\Omega$ to GND; $C_L = 200\text{ pF}$ to GND; $V_{REF} = V_{DD}$; all specifications T_{MIN} to T_{MAX} unless otherwise noted.

Table 2.

Parameter	A Grade ¹			B Grade ¹			Unit	Conditions/Comments ¹
	Min	Typ	Max	Min	Typ	Max		
STATIC PERFORMANCE ²								
AD5664								
Resolution	16			16			Bits	Guaranteed monotonic by design
Relative Accuracy		±8	±16		±6	±12	LSB	
Differential Nonlinearity			±1			±1	LSB	
AD5624								
Resolution				12			Bits	Guaranteed monotonic by design
Relative Accuracy					±0.5	±1	LSB	
Differential Nonlinearity						±0.25	LSB	
Zero Code Error		+2	+10		+2	+10	mV	All zeroes loaded to DAC register
Offset Error		±1	±10		±1	±10	mV	All ones loaded to DAC register
Full-Scale Error		−0.15	−1		−0.15	−1	% of FSR	
Gain Error			±1.5			±1.5	% of FSR	
Zero Code Error		±2			±2		μV/°C	of FSR/°C
Drift ³								
Gain Temperature Coefficient		±2.5			±2.5		ppm	
DC Power Supply Rejection Ratio		−100			−100		dB	DAC code = midscale; $V_{DD} \pm 10\%$
DC Crosstalk		10			10		μV	Due to full-scale output change $R_L = 2\text{ k}\Omega$ to GND or V_{DD}
		5			5		μV/mA	Due to load current change
		10			10		μV	Due to powering down (per channel)
OUTPUT CHARACTERISTICS ³								
Output Voltage Range	0	0	V_{DD}	0	0	V_{DD}	V	$R_L = \infty$
Capacitive Load Stability		2			2		nF	
		10			10		nF	
DC Output Impedance		0.5			0.5		Ω	$R_L = 2\text{ k}\Omega$
Short Circuit Current		30			30		mA	$V_{DD} = +5\text{ V}$
Power-Up Time		4			4		μs	Coming out of power-down mode; $V_{DD} = +5\text{ V}$
REFERENCE INPUTS								
Reference Current		40	75		40	75	μA	$V_{REF} = V_{DD} = +5.5\text{ V}$ (Per DAC channel)
		30	50		30	50	μA	$V_{REF} = V_{DD} = +3.6\text{ V}$ (Per DAC channel)
Reference Input Range	0		V_{DD}	0		V_{DD}	V	
Reference Input Impedance		14.6			14.6		kΩ	
LOGIC INPUTS ³								

Parameter	A Grade ¹			B Grade ¹			Unit	Conditions/Comments ¹
	Min	Typ	Max	Min	Typ	Max		
Input Current			±2			±2	μA	All digital inputs
V _{INL} , Input Low Voltage			0.8			0.8	V	V _{DD} = +5 V, +3 V
V _{INH} , Input High Voltage	2			2			V	V _{DD} = +5 V, +3 V
Pin Capacitance		3			3		pF	
POWER REQUIREMENTS								
V _{DD}	4.5		5.5	4.5		5.5	V	V _{IH} = V _{DD} and V _{IL} = GND
I _{DD} (Normal Mode) ⁴								
V _{DD} = 4.5 V to +5.5V		0.6	0.9		0.6	0.9	mA	
V _{DD} = 2.7V to +3.6 V		0.5	0.7		0.5	0.7	mA	
I _{DD} (All Power-Down Modes) ⁵								V _{IH} = V _{DD} and V _{IL} = GND
V _{DD} = 4.5 V to +5.5V		0.48	1		0.48	1	μA	
V _{DD} = 2.7V to +3.6 V		0.2	1		0.2	1	μA	

¹ Temperature range: A/B grade: –40°C to +105°C.

² Linearity calculated using a reduced code range: AD5664 (Code 512 to Code 65024); AD5624 (Code 32 to Code 4064). Output unloaded.

³ Guaranteed by design and characterization, not production tested.

⁴ Interface inactive. All DACs active. DAC outputs unloaded.

⁵ All four DACs powered down.

AC CHARACTERISTICS

$V_{DD} = +2.7\text{ V to }+5.5\text{ V}$; $R_L = 2\text{ k}\Omega$ to GND; $C_L = 200\text{ pF}$ to GND; $V_{ref} = V_{DD}$; all specifications T_{MIN} to T_{MAX} unless otherwise noted.

Parameter ^{1, 2}	Min	Typ	Max	Unit	Conditions/Comments ³
Output Voltage Settling Time					
AD5664		6	10	μs	$\frac{1}{4}$ to $\frac{3}{4}$ scale settling to $\pm 2\text{LSB}$
AD5624		6	10	μs	$\frac{1}{4}$ to $\frac{3}{4}$ scale settling to $\pm 0.25\text{LSB}$
Slew Rate		1.5		$\text{V}/\mu\text{s}$	
Digital-to-Analog Glitch Impulse		4		nV-s	1 LSB change around major carry
Digital Feedthrough		0.1		nV-s	
Digital Crosstalk		0.5		nV-s	
Analog Crosstalk		2.5		nV-s	
DAC-to-DAC Crosstalk		3		nV-s	
Multiplying Bandwidth		340		kHz	$V_{REF} = 2\text{ V} \pm 0.1\text{ V p-p}$
Total Harmonic Distortion		-80		dB	$V_{REF} = 2\text{ V} \pm 0.1\text{ V p-p}$, frequency = 10 kHz
Output Noise Spectral Density		120		$\text{nV}/\sqrt{\text{Hz}}$	DAC code = 8400 _H , 1 kHz
		100		$\text{nV}/\sqrt{\text{Hz}}$	DAC code = 8400 _H , 10 kHz
Output Noise		15		$\mu\text{V p-p}$	0.1 Hz to 10 Hz

¹ Guaranteed by design and characterization, not production tested.

² Temperature range: -40°C to $+105^\circ\text{C}$; typical at $+25^\circ\text{C}$.

³ See the Terminology section.

TIMING CHARACTERISTICS

All input signals are specified with $t_r = t_f = 1 \text{ ns/V}$ (10% to 90% of V_{DD}) and timed from a voltage level of $(V_{IL} + V_{IH})/2$. See Figure 2. $V_{DD} = 2.7 \text{ V}$ to 5.5 V ; all specifications T_{MIN} to T_{MAX} , unless otherwise noted. Guaranteed by design and test; not production tested.

Table 3.

Parameter	Limit at T_{MIN}, T_{MAX} $V_{DD} = 2.7 \text{ V to } 5.5 \text{ V}$	Unit	Conditions/Comments
t_1^1	20	ns min	SCLK cycle time
t_2	9	ns min	SCLK high time
t_3	9	ns min	SCLK low time
t_4	13	ns min	$\overline{\text{SYNC}}$ to SCLK falling edge setup time
t_5	4	ns min	Data setup time
t_6	4	ns min	Data hold time
t_7	0	ns min	SCLK falling edge to $\overline{\text{SYNC}}$ rising edge
t_8	15	ns min	Minimum $\overline{\text{SYNC}}$ high time
t_9	13	ns min	$\overline{\text{SYNC}}$ rising edge to SCLK fall ignore
t_{10}	0	ns min	SCLK falling edge to $\overline{\text{SYNC}}$ fall ignore

¹ Maximum SCLK frequency is 50 MHz at $V_{DD} = 2.7 \text{ V}$ to 5.5 V .

TIMING DIAGRAM

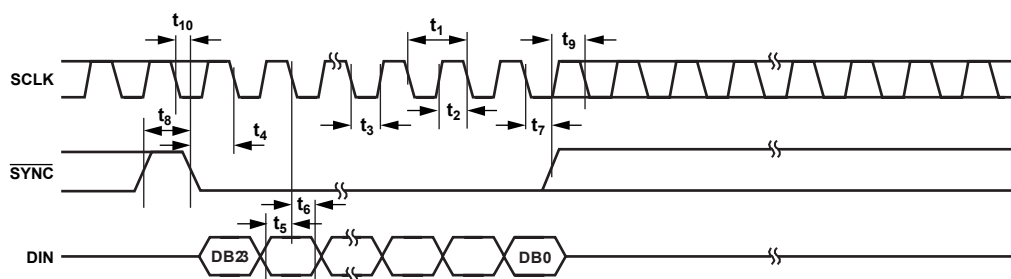


Figure 2. Serial Write Operation

04777-602

ABSOLUTE MAXIMUM RATINGS

$T_A = 25^\circ\text{C}$, unless otherwise noted.

Table 4.

Parameter	Rating
V_{DD} to GND	$-0.3\text{ V to }+7\text{ V}$
V_{OUT} to GND	$-0.3\text{ V to }V_{DD} + 0.3\text{ V}$
V_{REF} to GND	$-0.3\text{ V to }V_{DD} + 0.3\text{ V}$
Digital Input Voltage to GND	$-0.3\text{ V to }V_{DD} + 0.3\text{ V}$
Operating Temperature Range	
Industrial (A Grade, B Grade)	$-40^\circ\text{C to }+105^\circ\text{C}$
Storage Temperature Range	$-65^\circ\text{C to }+150^\circ\text{C}$
Junction Temperature (T_J max)	150°C
Power Dissipation	$(T_J \text{ max} - T_A)/\theta_{JA}$
LFCSP Package (4-Layer Board)	
θ_{JA} Thermal Impedance	61°C/W
MSOP Package (4-Layer Board)	
θ_{JA} Thermal Impedance	142°C/W
θ_{JC} Thermal Impedance	43.7°C/W
Reflow Soldering Peak Temperature	
Pb-Free	$260^\circ\text{C} \pm 5^\circ\text{C}$

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

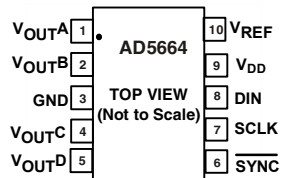


Figure 3. MSOP and LFCSP Pin Configuration

Table 5. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	V _{OUTA}	Analog Output Voltage from DAC A. The output amplifier has rail-to-rail operation.
2	V _{OUTB}	Analog Output Voltage from DAC B. The output amplifier has rail-to-rail operation.
3	GND	Ground Reference Point for All Circuitry on the Part.
4	V _{OUTC}	Analog Output Voltage from DAC C. The output amplifier has rail-to-rail operation.
5	V _{OUTD}	Analog Output Voltage from DAC D. The output amplifier has rail-to-rail operation.
6	$\overline{\text{SYNC}}$	Active Low Control Input. This is the frame synchronization signal for the input data. When $\overline{\text{SYNC}}$ goes low, it powers on the SCLK and DIN buffers and enables the input shift register. Data is transferred in on the falling edges of the next 24 clocks. If $\overline{\text{SYNC}}$ is taken high before the 24 th falling edge, the rising edge of $\overline{\text{SYNC}}$ acts as an interrupt and the write sequence is ignored by the device.
7	SCLK	Serial Clock Input. Data is clocked into the input shift register on the falling edge of the serial clock input. Data can be transferred at rates up to 50 MHz.
8	DIN	Serial Data Input. This device has a 24-bit shift register. Data is clocked into the register on the falling edge of the serial clock input.
9	V _{DD}	Power Supply Input. These parts can be operated from 2.7 V to 5.5 V, and the supply should be decoupled with a 10 μ F capacitor in parallel with a 0.1 μ F capacitor to GND.
10	V _{REF}	Reference Voltage Input.

TYPICAL PERFORMANCE CHARACTERISTICS

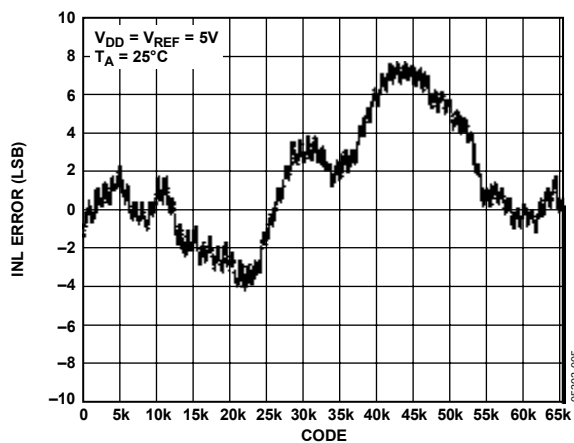


Figure 4. INL AD5664

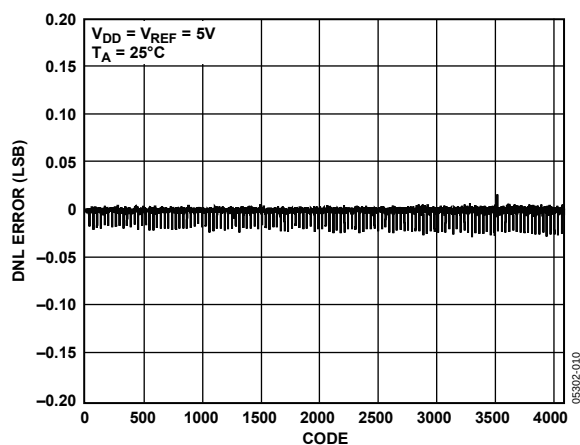


Figure 7. DNL AD5624

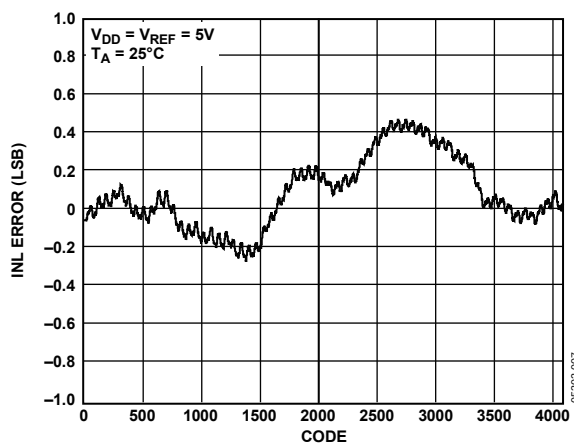


Figure 5. INL AD5624

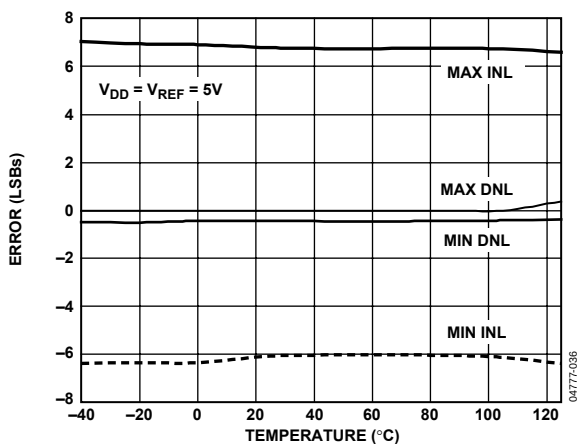


Figure 8. INL Error and DNL Error vs. Temperature

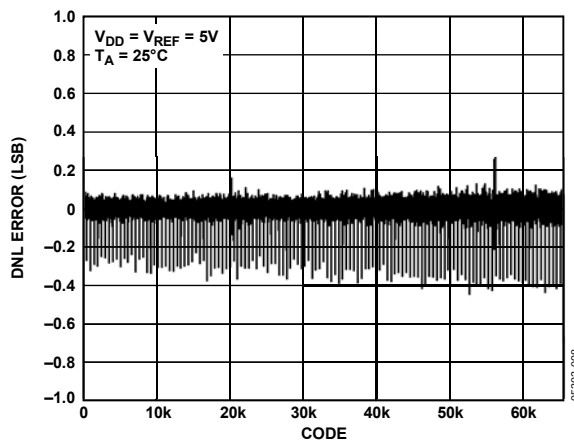
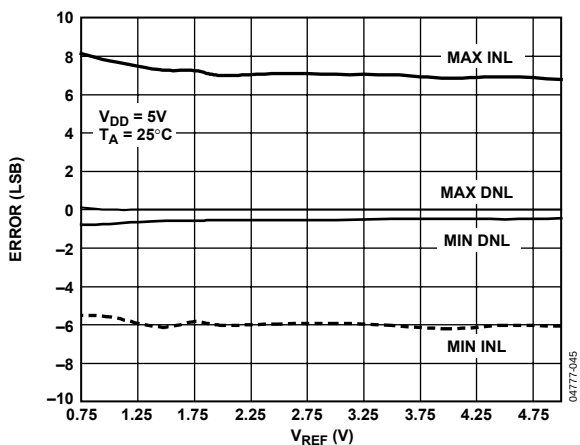


Figure 6. DNL AD5664

Figure 9. INL and DNL Error vs. V_{REF}

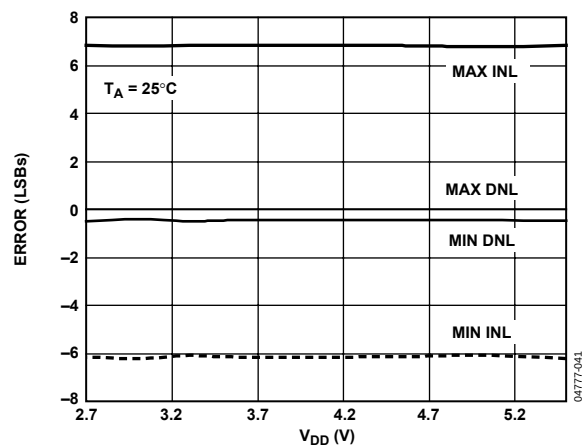


Figure 10. INL and DNL Error vs. Supply

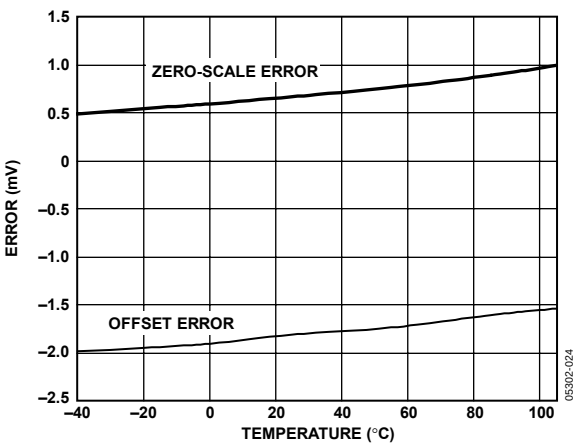


Figure 12. Zero-Scale and Offset Error vs. Temperature

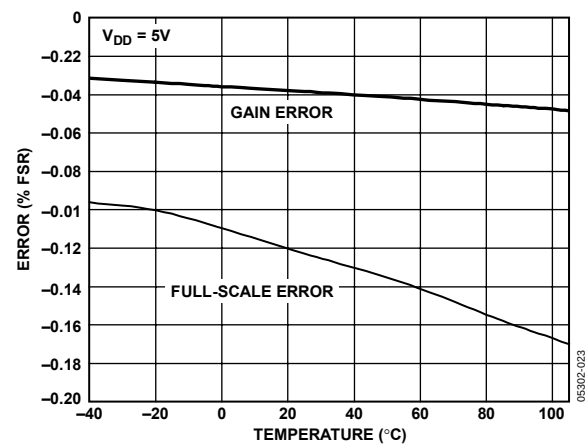


Figure 11. Gain Error and Full-Scale Error vs. Temperature

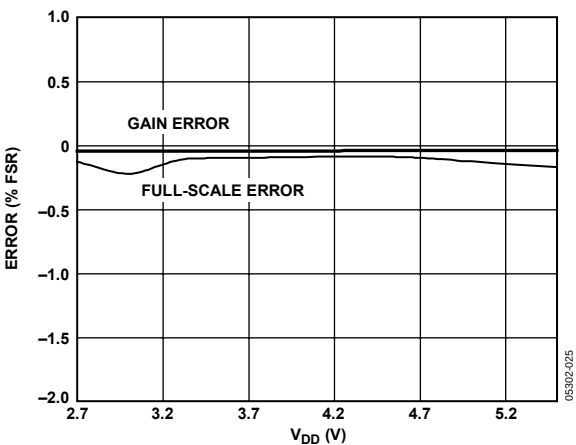


Figure 13. Gain Error and Full-Scale Error vs. Supply

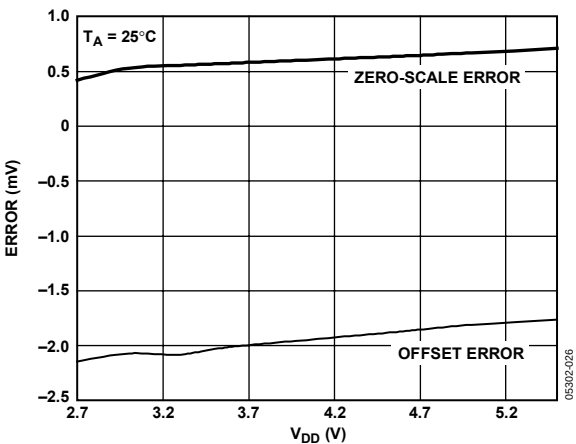


Figure 14. Zero-Scale and Offset Error vs. Supply

TBD

Figure 15. I_{DD} Histogram with $V_{DD} = 5.5\text{ V}$

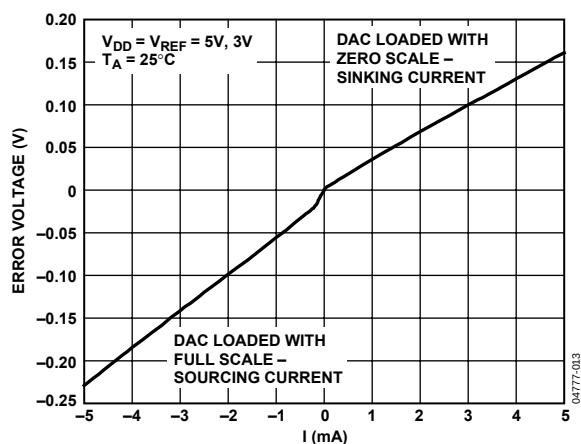


Figure 16. Headroom at Rails vs. Source and Sink Current

TBD

Figure 17. Supply Current vs. Code

TBD

Figure 18. Supply Current vs. Temperature

TBD

Figure 19. Supply Current vs. Supply Voltage

TBD

Figure 20. Supply Current vs. Logic Input Voltage

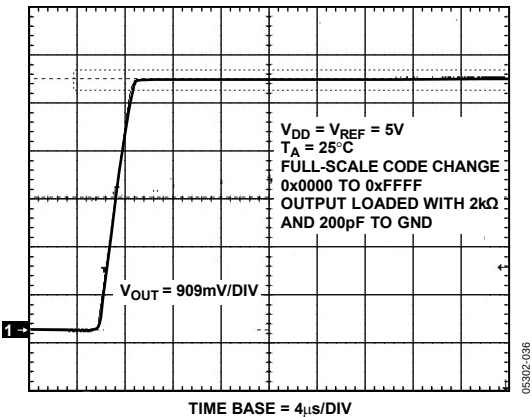


Figure 21. Full-Scale Settling Time, 5 V

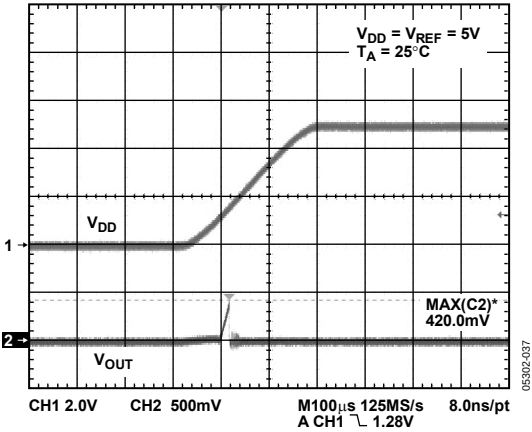


Figure 22. Power-On Reset to 0 V

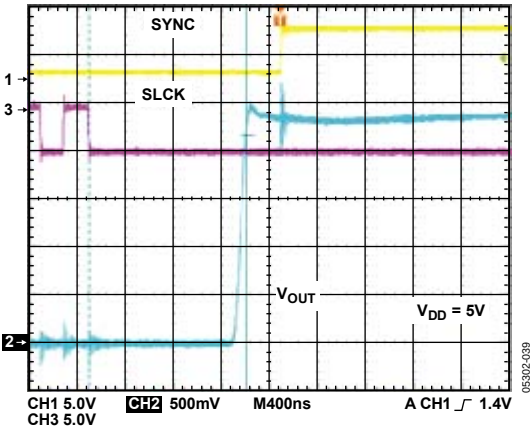


Figure 23. Exiting Power-Down to Midscale

TBD

Figure 24. Digital-to-Analog Glitch Impulse (Negative)

TBD

Figure 25. Digital-to-Analog Glitch Impulse (Positive)

TBD

Figure 26. Digital Feedthrough

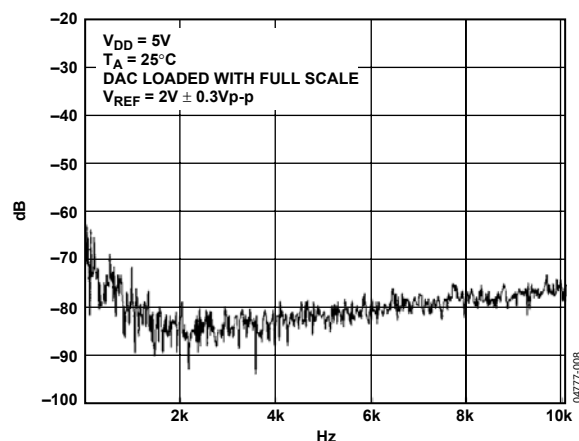


Figure 27. Total Harmonic Distortion

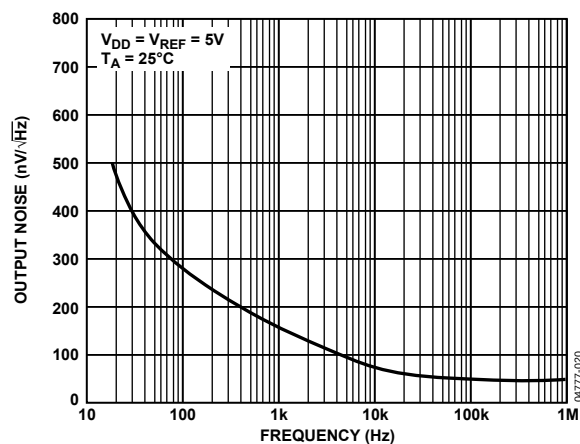


Figure 30. Noise Spectral Density

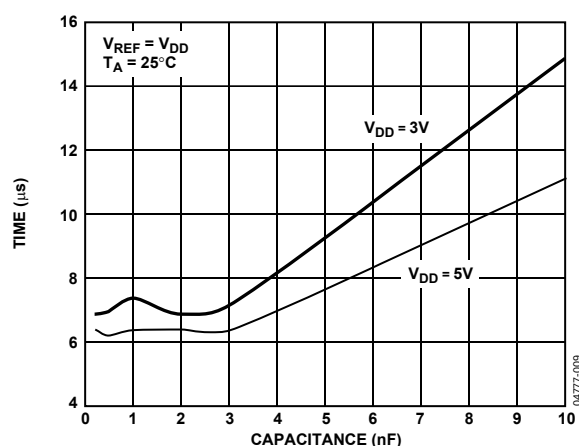


Figure 28. Settling Time vs. Capacitive Load

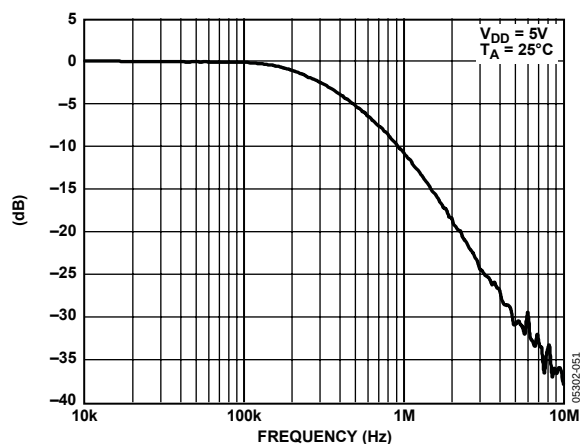


Figure 31. Multiplying Bandwidth

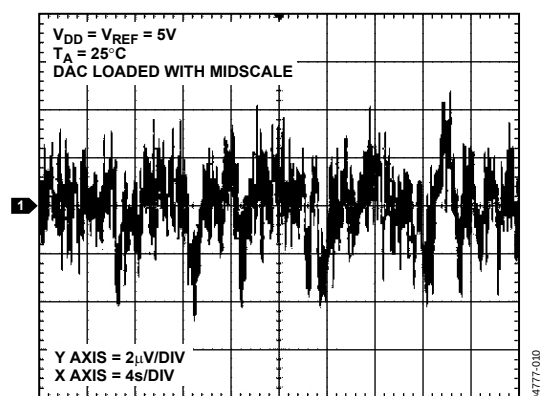


Figure 29. 0.1 Hz to 10 Hz Output Noise Plot

TERMINOLOGY

Relative Accuracy or Integral Nonlinearity (INL)

For the DAC, relative accuracy or integral nonlinearity is a measurement of the maximum deviation, in LSBs, from a straight line passing through the endpoints of the DAC transfer function. A typical INL vs. code plot can be seen in **Error!**

Reference source not found..

Differential Nonlinearity (DNL)

Differential nonlinearity is the difference between the measured change and the ideal 1 LSB change between any two adjacent codes. A specified differential nonlinearity of ± 1 LSB maximum ensures monotonicity. This DAC is guaranteed monotonic by design. A typical DNL vs. code plot can be seen in **Error!**

Reference source not found..

Zero-Code Error

Zero-code error is a measurement of the output error when zero code (0x0000) is loaded to the DAC register. Ideally, the output should be 0 V. The zero-code error is always positive in the AD5624/AD5664 because the output of the DAC cannot go below 0 V. It is due to a combination of the offset errors in the DAC and the output amplifier. Zero-code error is expressed in mV. A plot of zero-code error vs. temperature can be seen in **Error!**

Reference source not found..

Full-Scale Error

Full-scale error is a measurement of the output error when full-scale code (0xFFFF) is loaded to the DAC register. Ideally, the output should be $V_{DD} - 1$ LSB. Full-scale error is expressed in percent of full-scale range. A plot of full-scale error vs. temperature can be seen in **Error!**

Reference source not found..

Gain Error

This is a measure of the span error of the DAC. It is the deviation in slope of the DAC transfer characteristic from ideal expressed as a percent of the full-scale range.

Zero-Code Error Drift

This is a measurement of the change in zero-code error with a change in temperature. It is expressed in $\mu\text{V}/^\circ\text{C}$.

Gain Temperature Coefficient

This is a measurement of the change in gain error with changes in temperature. It is expressed in (ppm of full-scale range)/ $^\circ\text{C}$.

Offset Error

Offset error is a measure of the difference between V_{OUT} (actual) and V_{OUT} (ideal) expressed in mV in the linear region of the transfer function. Offset error is measured on the AD5624/AD5664 with code 512 loaded in the DAC register. It can be negative or positive.

DC Power Supply Rejection Ratio (PSRR)

This indicates how the output of the DAC is affected by changes in the supply voltage. PSRR is the ratio of the change in V_{OUT} to a change in V_{DD} for full-scale output of the DAC. It is measured in dB. V_{REF} is held at 2 V, and V_{DD} is varied by $\pm 10\%$.

Output Voltage Settling Time

This is the amount of time it takes for the output of a DAC to settle to a specified level for a $\frac{1}{4}$ to $\frac{3}{4}$ full-scale input change and is measured from the 24th falling edge of SCLK.

Digital-to-Analog Glitch Impulse

Digital-to-analog glitch impulse is the impulse injected into the analog output when the input code in the DAC register changes state. It is normally specified as the area of the glitch in nV-s, and is measured when the digital input code is changed by 1 LSB at the major carry transition (0x7FFF to 0x10000). See Figure 24 and Figure 25.

Digital Feedthrough

Digital feedthrough is a measure of the impulse injected into the analog output of the DAC from the digital inputs of the DAC, but is measured when the DAC output is not updated. It is specified in nV-s, and measured with a full-scale code change on the data bus, that is, from all 0s to all 1s and vice versa.

Total Harmonic Distortion (THD)

This is the difference between an ideal sine wave and its attenuated version using the DAC. The sine wave is used as the reference for the DAC, and the THD is a measurement of the harmonics present on the DAC output. It is measured in dB.

Noise Spectral Density

This is a measurement of the internally generated random noise. Random noise is characterized as a spectral density (voltage per $\sqrt{\text{Hz}}$). It is measured by loading the DAC to midscale and measuring noise at the output. It is measured in $\text{nV}/\sqrt{\text{Hz}}$. A plot of Noise Spectral Density can be seen in **Error!**

Reference source not found..

DC Crosstalk

DC crosstalk is the dc change in the output level of one DAC in response to a change in the output of another DAC. It is measured with a full-scale output change on one DAC (or soft power-down and power-up) while monitoring another DAC kept at midscale. It is expressed in microvolts.

DC crosstalk due to load current change is a measure of the impact that a change in load current on one DAC has to another DAC kept at midscale. It is expressed in microvolts per milliamp.

Digital Crosstalk

This is the glitch impulse transferred to the output of one DAC at midscale in response to a full-scale code change (all 0s to all 1s and vice versa) in the input register of another DAC. It is measured in standalone mode and is expressed in nV-s.

Analog Crosstalk

This is the glitch impulse transferred to the output of one DAC due to a change in the output of another DAC. It is measured by loading one of the input registers with a full-scale code change (all 0s to all 1s and vice versa) while keeping LDAC high. Then pulse LDAC low and monitor the output of the DAC whose digital code was not changed. The area of the glitch is expressed in nV-s.

DAC-to-DAC Crosstalk

This is the glitch impulse transferred to the output of one DAC due to a digital code change and subsequent output change of another DAC. This includes both digital and analog crosstalk. It is measured by loading one of the DACs with a full-scale code change (all 0s to all 1s and vice versa) with LDAC low and monitoring the output of another DAC. The energy of the glitch is expressed in nV-s.

Multiplying Bandwidth

The amplifiers within the DAC have a finite bandwidth. The multiplying bandwidth is a measure of this. A sine wave on the reference (with full-scale code loaded to the DAC) appears on the output. The multiplying bandwidth is the frequency at which the output amplitude falls to 3 dB below the input.

THEORY OF OPERATION

D/A SECTION

The AD5624/AD5664 DAC is fabricated on a CMOS process. The architecture consists of a string DAC followed by an output buffer amplifier. Figure 32 shows a block diagram of the DAC architecture.

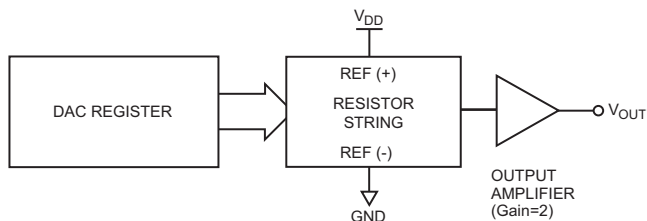


Figure 32. DAC Architecture

Since the input coding to the DAC is straight binary, the ideal output voltage is given by

$$V_{OUT} = V_{REFIN} \times \left(\frac{D}{2^N} \right)$$

where D = decimal equivalent of the binary code that is loaded to the DAC register;

0 - 4095 for AD5624 (12 bit)

0 - 65535 for AD5664 (16 bit)

N = the DAC resolution

RESISTOR STRING

The resistor string section is shown in Figure 33. It is simply a string of resistors, each of value R . The code loaded to the DAC register determines at which node on the string the voltage is tapped off to be fed into the output amplifier. The voltage is tapped off by closing one of the switches connecting the string to the amplifier. Because it is a string of resistors, it is guaranteed monotonic.

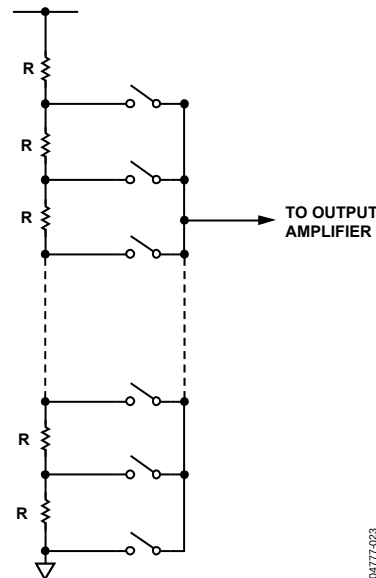


Figure 33. Resistor String

04777-023

OUTPUT AMPLIFIER

The output buffer amplifier can generate rail-to-rail voltages on its output, which gives an output range of 0 V to V_{DD} . It can drive a load of 2 k Ω in parallel with 1000 pF to GND. The source and sink capabilities of the output amplifier can be seen in **Error!**

Reference source not found.. The slew rate is 1.5 V/ μ s with a $\frac{1}{4}$ to $\frac{3}{4}$ full-scale settling time of 10 μ s.

SERIAL INTERFACE

The AD5624/AD5664 has a 3-wire serial interface ($\overline{\text{SYNC}}$, SCLK, and DIN) that is compatible with SPI, QSPI, and MICROWIRE interface standards as well as with most DSPs. See Figure 2 for a timing diagram of a typical write sequence.

The write sequence begins by bringing the $\overline{\text{SYNC}}$ line low. Data from the DIN line is clocked into the 24-bit shift register on the falling edge of SCLK. The serial clock frequency can be as high as 50 MHz, making the AD5624/AD5664 compatible with high speed DSPs. On the 24th falling clock edge, the last data bit is clocked in and the programmed function is executed, that is, a change in DAC register contents and/or a change in the mode of operation. At this stage, the $\overline{\text{SYNC}}$ line can be kept low or be brought high. In either case, it must be brought high for a minimum of 33 ns before the next write sequence so that a falling edge of $\overline{\text{SYNC}}$ can initiate the next write sequence. Since the $\overline{\text{SYNC}}$ buffer draws more current when $V_{IN} = 2.0$ V than it does when $V_{IN} = 0.10$ V, $\overline{\text{SYNC}}$ should be idled low between write sequences for even lower power operation. As mentioned previously it must, however, be brought high again just before the next write sequence.

INPUT SHIFT REGISTER

The input shift register is 24 bits wide. The first two bits are don't cares. The next three are the Command bits C2 – C0, (see Table 1)) followed by the 3-bit DAC address A2-A0, (see Table 2) and finally the 12-16-bit data word. The data word comprises the 16- 12- bit input code followed by 0 or 4 don't care bits, the AD5664 and AD5624 respectively. (see Figure 34). These are transferred to the DAC register on the 24th falling edge of SCLK.

SYNC INTERRUPT

In a normal write sequence, the $\overline{\text{SYNC}}$ line is kept low for at least 24 falling edges of SCLK, and the DAC is updated on the 24th falling edge. However, if $\overline{\text{SYNC}}$ is brought high before the 24th falling edge, then this acts as an interrupt to the write sequence. The shift register is reset and the write sequence is seen as invalid. Neither an update of the DAC register contents nor a change in the operating mode occurs (see Figure 36).

POWER-ON RESET

The AD5624/AD5664 family contains a power-on reset circuit that controls the output voltage during power-up. The AD5624/AD5664 DAC outputs power up to 0 V and the output remains there until a valid write sequence is made to the DAC. This is useful in applications where it is important to know the state of the output of the DAC while it is in the process of powering up.

Software Reset

The AD5624/AD5664 contains a Software Reset function. Command 110 is reserved for the Software Reset function, see Table 1. The Software Reset command contains two reset modes that are software-programmable by setting bit DB0 in the control register.

Table 6 shows how the state of the bit corresponds to the mode of operation of the device.

Table 6. Software Reset Modes for the AD5624/AD5664

DB0	Registers reset to zero
0	DAC Register Input Register
1 (Power-on -Reset)	DAC Register Input Register /LDAC Register Powerdown Register

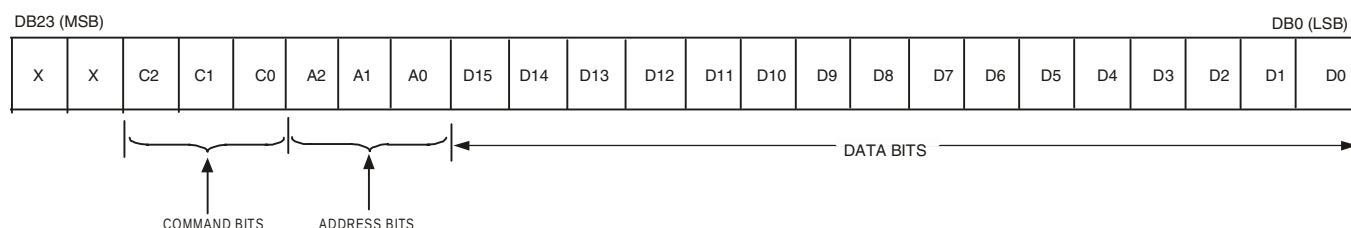


Figure 34. AD5664 Input Register Contents

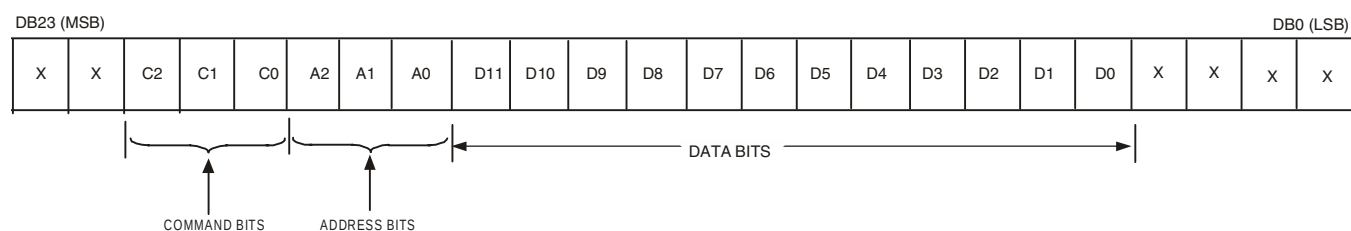


Figure 35. AD5624 Input Register Contents

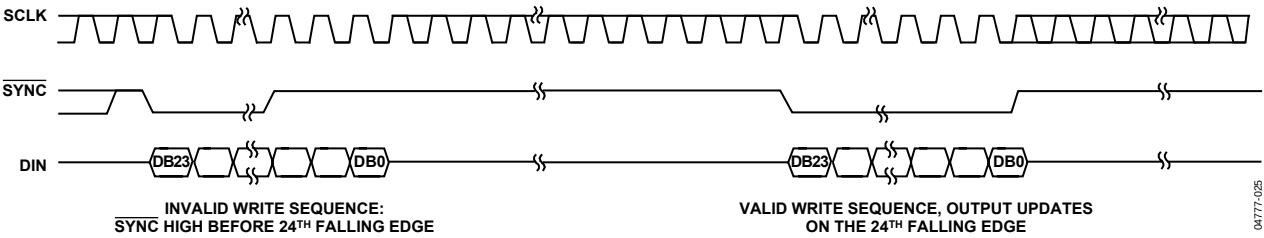


Figure 36. SYNC Interrupt Facility

Table 7. Command Definition

C2	C1	C0	Command
0	0	0	Write to Input Register n
0	0	1	Update DAC Register n
0	1	0	Write to Input Register n, Update All
0	1	1	Write to and Update DAC channel n
1	0	0	Power Down DAC (Power-up)
1	0	1	Reset (Power-on-Reset)
1	1	0	Load LDAC Register
1	1	1	Reserved

Table 8. Address Command

A2	A1	A0	ADDRESS (n)
0	0	0	DAC A
0	0	1	DAC B
0	1	0	DAC C
0	1	1	DAC D
1	1	1	All DACs

Table 9. 24-Bit Input Shift Register Contents of Power Up/Down Function

MSB													LSB
DB23 to DB22	DB21	DB20	DB19	DB18	DB17	DB16	DB15 to DB6	DB 5	DB 4	DB3	DB2	DB1	DB0
x	1	0	0	x	x	x	x	PD1	PD0	DAC D	DAC C	DAC B	DAC A
Don't Cares	COMMAND BITS (C2-C0)			ADDRESS BITS (A2 to A0)			Don't Cares	Power-down mode		Power down/up channel selection, set bit to 1 to select channel			

POWER-DOWN MODES

The AD5624/AD5664 contains four separate modes of operation. Command 100 is reserved for the Power-Down function. See Table 1. These modes are software-programmable by setting two bits (DB5 and DB4) in the control register. Table 6 shows how the state of the bits corresponds to the mode of operation of the device. Any or all DACs, (DacD to DacA) may be powered down to the selected mode by setting the corresponding 4 bits (DB3,2,1,0) to a "1". By executing the same Command 100, any combination of DACs may be powered up by setting the bits (DB5 and DB4) to Normal Operation mode. Again, to select which combination of DAC channels to power-up set the corresponding 4 bits (DB3, 2, 1, 0) to a "1". See Table 9 for contents of the Input Shift Register during power down/up operation.

The DAC output will power-up to the value in the input register while /LDAC is low. If /LDAC is high, the DAC output will power-up to the value held in the DAC register before power-down.

Table 10. Modes of Operation for the AD5624/AD5664

DB5	DB4	Operating Mode
0	0	Normal Operation
		Power-Down Modes
0	1	1 k Ω to GND
1	0	100 k Ω to GND
1	1	Three-State

When both bits are set to 0, the part works normally with its normal power consumption of 500 μ A at 5 V. However, for the three power-down modes, the supply current falls to 480 nA at 5 V (100 nA at 3 V). Not only does the supply current fall, but the output stage is also internally switched from the output of the amplifier to a resistor network of known values. This has the advantage that the output impedance of the part is known while the part is in power-down mode.

Table 11. Software LDAC Definition

Load DAC Register

/LDACBITS (DB3 to DB0)	/LDAC Operation
0	Normal operation - default
1	The DAC registers are updated after new data is read in on the falling edge of the 24th SCLK pulse.

Table 12. 24-Bit Input Shift Register Contents for /LDAC Overwrite Function

MSB											LSB
DB23 to DB22	DB21	DB20	DB19	DB18	DB17	DB16	DB15 to DB4	DB3	DB2	DB1	DB0
x	1	0	1	x	x	x	x	DacD	DacC	DacB	DacA
Don't Cares	COMMAND BITS (C2 to C0)			ADDRESS BITS (A3 to A0)			Don't Cares	Setting bit to "1" selects DAC channel for /LDAC operation mode			
				Don't cares							

The outputs can either be connected internally to GND through a 1 k Ω or 100 k Ω resistor, or left open-circuited (three-state) (see Figure 37).

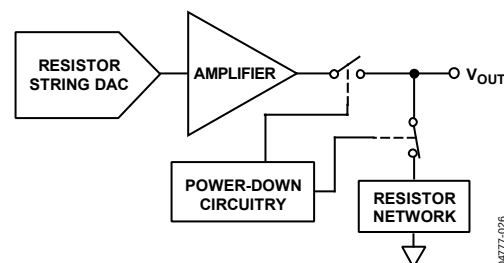


Figure 37. Output Stage During Power-Down

The bias generator, the output amplifier, the resistor string, and other associated linear circuitry are shut down when power-down mode is activated. However, the contents of the DAC register are unaffected when in power-down. The time to exit power-down is typically 4 μ s for $V_{DD} = 5$ V and for $V_{DD} = 3$ V (see **Error! Reference source not found.**).

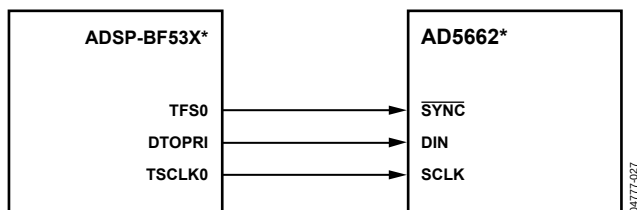
LDAC FUNCTION

The AD5624/AD5664 does not have a hardware /LDAC pin. Writing to the DAC using command 110, allows one to perform a software /LDAC on any or all of the DAC channels. The DAC channels are selected by setting the bits of the 4-bit /LDAC register (DB3,DB2, DB1,DB0). See Table 8 for the software /LDAC mode of operation. Setting the /LDAC bit to a "1" means the DAC registers are automatically updated after new data is read in on the falling edge of the 24th SCLK pulse. This is equivalent to having an /LDAC hardware pin tied permanently low for the selected DAC channel. See Table 12 for contents of the Input Shift Register during the /LDAC overwrite mode of operation.

MICROPROCESSOR INTERFACING

AD5624/AD5664 to Blackfin® ADSP-BF53X Interface

Figure 38 shows a serial interface between the AD5624/AD5664 and the Blackfin ADSP-BF53X microprocessor. The ADSP-BF53X processor family incorporates two dual-channel synchronous serial ports, SPORT1 and SPORT0, for serial and multiprocessor communications. Using SPORT0 to connect to the AD5624/AD5664, the setup for the interface is as follows. DTOPRI drives the DIN pin of the AD5624/AD5664, while TSCLK0 drives the SCLK of the part. The SYNC is driven from TFS0.



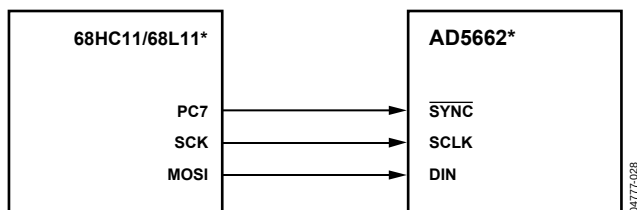
*ADDITIONAL PINS OMITTED FOR CLARITY

Figure 38. AD5624/AD5664 to Blackfin ADSP-BF53X Interface

AD5624/AD5664 to 68HC11/68L11 Interface

Figure 39 shows a serial interface between the AD5624/AD5664 and the 68HC11/68L11 microcontroller. SCK of the 68HC11/68L11 drives the SCLK of the AD5624/AD5664, while the MOSI output drives the serial data line of the DAC.

The SYNC signal is derived from a port line (PC7). The setup conditions for correct operation of this interface are as follows. The 68HC11/68L11 is configured with its CPOL bit as a 0 and its CPHA bit as a 1. When data is being transmitted to the DAC, the SYNC line is taken low (PC7). When the 68HC11/68L11 is configured as described above, data appearing on the MOSI output is valid on the falling edge of SCK. Serial data from the 68HC11/68L11 is transmitted in 10-bit bytes with only eight falling clock edges occurring in the transmit cycle. Data is transmitted MSB first. In order to load data to the AD5624/AD5664, PC7 is left low after the first eight bits are transferred, and a second serial write operation is performed to the DAC; PC7 is taken high at the end of this procedure.

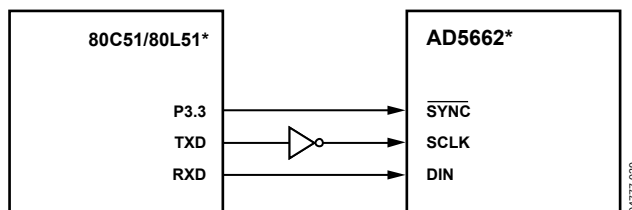


*ADDITIONAL PINS OMITTED FOR CLARITY

Figure 39. AD5624/AD5664 to 68HC11/68L11 Interface

AD5624/AD5664 to 80C51/80L51 Interface

Figure 40 shows a serial interface between the AD5624/AD5664 and the 80C51/80L51 microcontroller. The setup for the interface is as follows. TXD of the 80C51/80L51 drives SCLK of the AD5624/AD5664, while RXD drives the serial data line of the part. The SYNC signal is again derived from a bit-programmable pin on the port. In this case, port line P3.3 is used. When data is to be transmitted to the AD5624/AD5664, P3.3 is taken low. The 80C51/80L51 transmits data in 10-bit bytes only; thus only eight falling clock edges occur in the transmit cycle. To load data to the DAC, P3.3 is left low after the first eight bits are transmitted, and a second write cycle is initiated to transmit the second byte of data. P3.3 is taken high following the completion of this cycle. The 80C51/80L51 outputs the serial data in a format that has the LSB first. The AD5624/AD5664 must receive data with the MSB first. The 80C51/80L51 transmit routine should take this into account.

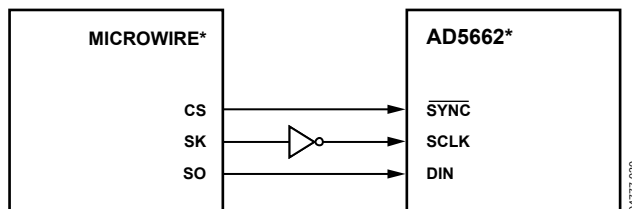


*ADDITIONAL PINS OMITTED FOR CLARITY

Figure 40. AD5624/AD5664 to 80C51/80L51 Interface

AD5624/AD5664 to MICROWIRE Interface

Figure 41 shows an interface between the AD5624/AD5664 and any MICROWIRE-compatible device. Serial data is shifted out on the falling edge of the serial clock and is clocked into the AD5624/AD5664 on the rising edge of the SK.



*ADDITIONAL PINS OMITTED FOR CLARITY

Figure 41. AD5624/AD5664 to MICROWIRE Interface

APPLICATIONS

CHOOSING A REFERENCE FOR THE AD5624/AD5664

To achieve the optimum performance from the AD5624/AD5664, thought should be given to the choice of a precision voltage reference. The AD5624/AD5664 has only one reference input, V_{REF} . The voltage on the reference input is used to supply the positive input to the DAC. Therefore any error in the reference is reflected in the DAC.

When choosing a voltage reference for high accuracy applications, the sources of error are initial accuracy, ppm drift, long term drift, and output voltage noise. Initial accuracy on the output voltage of the DAC leads to a full-scale error in the DAC. To minimize these errors, a reference with high initial accuracy is preferred. Also, choosing a reference with an output trim adjustment, such as the ADR423, allows a system designer to trim system errors out by setting a reference voltage to a voltage other than the nominal. The trim adjustment can also be used at temperature to trim out any error.

Long-term drift is a measurement of how much the reference drifts over time. A reference with a tight long-term drift specification ensures that the overall solution remains relatively stable during its entire lifetime.

The temperature coefficient of a reference's output voltage affect INL, DNL, and TUE. A reference with a tight temperature coefficient specification should be chosen to reduce temperature dependence of the DAC output voltage in ambient conditions.

In high accuracy applications, which have a relatively low noise budget, reference output voltage noise needs to be considered. It is important to choose a reference with as low an output noise voltage as practical for the system noise resolution required. Precision voltage references such as the ADR425 produce low output noise in the 0.1 Hz to 10 Hz range. Examples of recommended precision references for use as supply to the AD5624/AD5664 are shown in the Table 13.

USING A REFERENCE AS A POWER SUPPLY FOR THE AD5624/AD5664

Because the supply current required by the AD5624/AD5664 is extremely low, an alternative option is to use a voltage reference to supply the required voltage to the part (see Figure 42). This is especially useful if the power supply is quite noisy, or if the system supply voltages are at some value other than 5 V or 3 V, for example, 15 V. The voltage reference outputs a steady supply voltage for the AD5624/AD5664; see Table 13 for a suitable reference. If the low dropout REF195 is used, it must supply 500 μ A of current to the AD5624/AD5664, with no load on the output of the DAC. When the DAC output is loaded, the REF195 also needs to supply the current to the load. The total current required (with a 5 k Ω load on the DAC output) is

$$500 \mu\text{A} + (5 \text{ V} / 5 \text{ k}\Omega) = 1.5 \text{ mA}$$

The load regulation of the REF195 is typically 2 ppm/mA, which results in a 3 ppm (15 μ V) error for the 1.5 mA current drawn from it. This corresponds to a 0.196 LSB error.

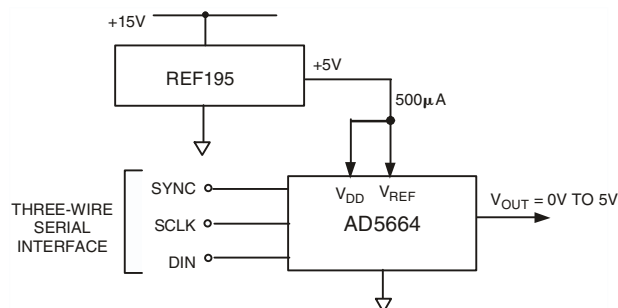


Figure 42. REF195 as Power Supply to the AD5624/AD5664

Table 13. Partial List of Precision References for Use with the AD5624/AD5664

Part No.	Initial Accuracy (mV max)	Temp Drift (ppm/°C max)	0.1 Hz to 10 Hz Noise (μ V p-p typ)	V _{OUT} (V)
ADR425	±2	3	3.4	5
ADR395	±6	25	5	5
REF195	±2	5	50	5
AD780	±2	3	4	2.5/3
ADR423	±2	3	3.4	3

BIPOLAR OPERATION USING THE AD5624/AD5664

The AD5624/AD5664 has been designed for single-supply operation, but a bipolar output range is also possible using the circuit in Figure 43. The circuit gives an output voltage range of ± 5 V. Rail-to-rail operation at the amplifier output is achievable using an AD1020 or an OP295 as the output amplifier.

The output voltage for any input code can be calculated as follows:

$$V_O = \left[V_{DD} \times \left(\frac{D}{65,536} \right) \times \left(\frac{R1 + R2}{R1} \right) - V_{DD} \times \left(\frac{R2}{R1} \right) \right]$$

where D represents the input code in decimal (0 to 65535).
With $V_{DD} = 5$ V, $R1 = R2 = 10$ k Ω ,

$$V_O = \left(\frac{10 \times D}{65,536} \right) - 5$$

This is an output voltage range of ± 5 V, with 0x0000 corresponding to a -5 V output, and 0xFFFF corresponding to a $+5$ V output.

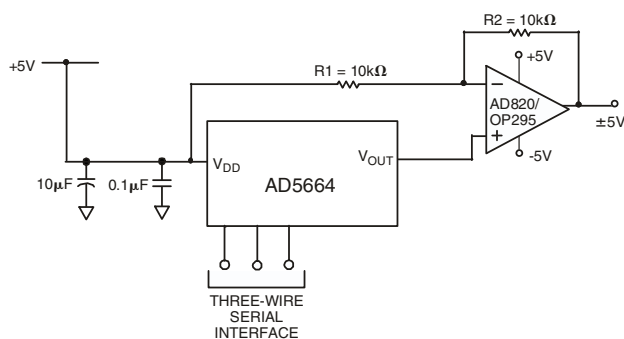


Figure 43. Bipolar Operation with the AD5624/AD5664

USING AD5624/AD5664 WITH A GALVANICALLY ISOLATED INTERFACE

In process-control applications in industrial environments, it is often necessary to use a galvanically isolated interface to protect and isolate the controlling circuitry from any hazardous common-mode voltages that might occur in the area where the DAC is functioning. Isocouplers provide isolation in excess of 3 kV. The AD5624/AD5664 uses a 3-wire serial logic interface, so the ADuM130x 3-channel digital isolator provides the required isolation (see Figure 44). The power supply to the part also needs to be isolated, which is done by using a transformer. On the DAC side of the transformer, a 5 V regulator provides the 5 V supply required for the AD5624/AD5664.

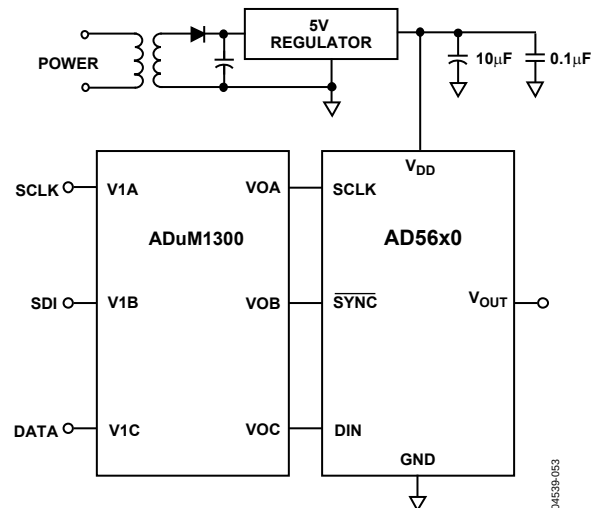


Figure 44. AD5624/AD5664 with a Galvanically Isolated Interface

POWER SUPPLY BYPASSING AND GROUNDING

When accuracy is important in a circuit, it is helpful to carefully consider the power supply and ground return layout on the board. The printed circuit board containing the AD5624/AD5664 should have separate analog and digital sections, each having its own area of the board. If the AD5624/AD5664 is in a system where other devices require an AGND-to-DGND connection, the connection should be made at one point only. This ground point should be as close as possible to the AD5624/AD5664.

The power supply to the AD5624/AD5664 should be bypassed with 10 μ F and 0.1 μ F capacitors. The capacitors should be located as close as possible to the device, with the 0.1 μ F capacitor ideally right up against the device. The 10 μ F capacitors are the tantalum bead type. It is important that the 0.1 μ F capacitor has low effective series resistance (ESR) and effective series inductance (ESI), for example, common ceramic types of capacitors. This 0.1 μ F capacitor provides a low impedance path to ground for high frequencies caused by transient currents due to internal logic switching.

The power supply line itself should have as large a trace as possible to provide a low impedance path and to reduce glitch effects on the supply line. Clocks and other fast switching digital signals should be shielded from other parts of the board by digital ground. Avoid crossover of digital and analog signals if possible. When traces cross on opposite sides of the board, ensure that they run at right angles to each other to reduce feedthrough effects through the board. The best board layout technique is the microstrip technique where the component side of the board is dedicated to the ground plane only and the signal traces are placed on the solder side. However, this is not always possible with a 2-layer board.

OUTLINE DIMENSIONS

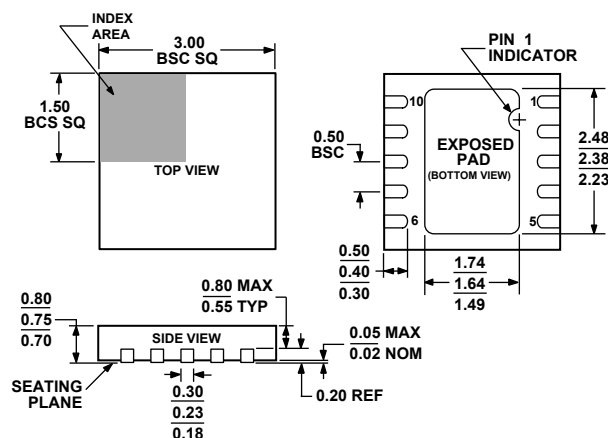
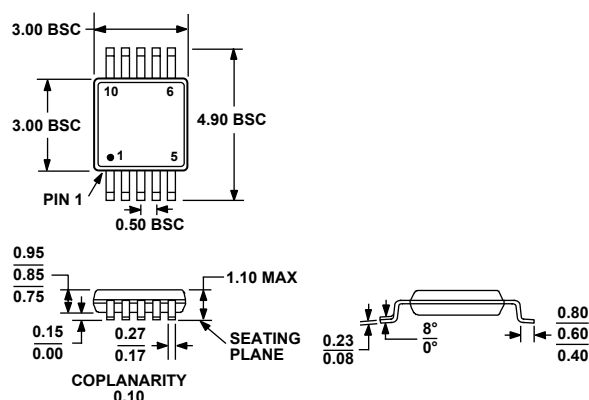


Figure 45. 10-Lead Lead Frame Chip Scale Package
(CP-10-9)

Dimensions shown in millimeters



COMPLIANT TO JEDEC STANDARDS MO-187BA

Figure 46. 10-Lead Mini Small Outline Package [MSOP]
(RM-10)

Dimensions shown in millimeters

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option	Accuracy
AD5664ARMZ	−40°C to +105°C	10-lead MSOP	RM-10	±16 LSB INL
AD5664BRMZ	−40°C to +105°C	10-lead MSOP	RM-10	±12 LSB INL
AD5664BCPZ	−40°C to +105°C	10-lead LFCSP	CP-10	±12 LSB INL
AD5624BRMZ	−40°C to +105°C	10-lead MSOP	RM-10	±1 LSB INL
AD5624BCPZ	−40°C to +105°C	10-lead LFCSP	CP-10	±1 LSB INL

NOTES