

**FEATURES**

- 16-channel DAC in 52-LQFP and 56-LFCSP
- Guaranteed monotonic to 16/14 bits
- Nominal output voltage range of -10 V to +10 V
- Multiple output spans available
- Temperature Monitoring Function
- Channel Monitoring Multiplexer
- GPIO Function
- System calibration function allowing user-programmable offset and gain
- Channel grouping and addressing features
- Data error checking feature

SPI compatible serial interface

2.5 V to 5.5 V digital interface

Power-on reset

 Digital reset ( $\overline{\text{RESET}}$ )

 Clear function to user-defined SIGGND ( $\overline{\text{CLR}}$  pin)

Simultaneous update of DAC outputs (LDAC pin)

**APPLICATIONS**

- Instrumentation
- Industrial control systems
- Level setting in automatic test equipment (ATE)
- Variable optical attenuators (VOA)
- Optical Line Cards

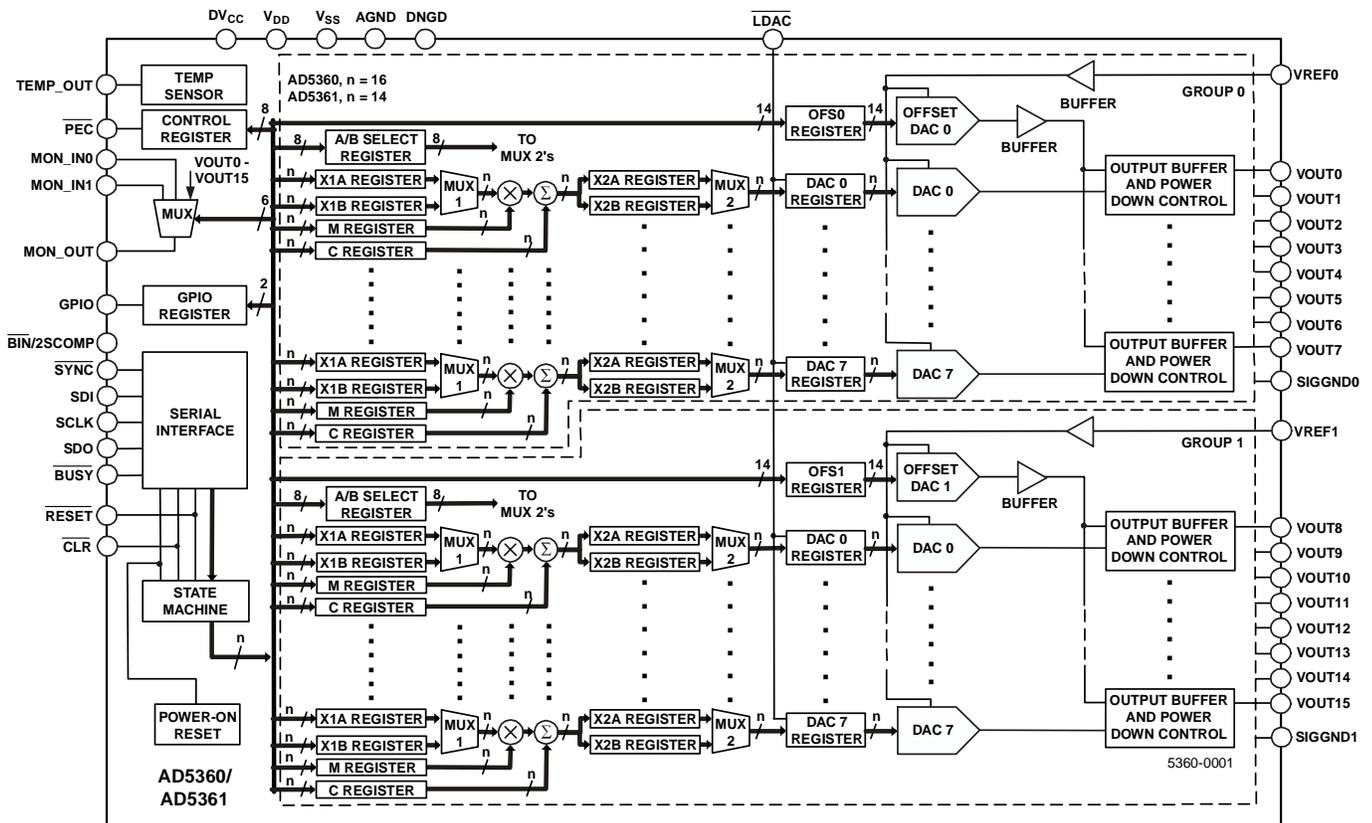
**FUNCTIONAL BLOCK DIAGRAM**


Figure 1.

**Rev. PrF**

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## REVISION HISTORY

## GENERAL DESCRIPTION

The AD5360/AD5361 contains 16, 16/14-bit DACs in a single, 56-lead, LFCSP or 52-lead LQFP package. It provides buffered voltage outputs with a span 4 times the reference voltage. The gain and offset of each DAC can be independently trimmed to remove errors. For even greater flexibility, the device is divided into two groups of 8 DACs, and the output range of each group can be independently adjusted by an offset DAC.

The AD5360/AD5361 offers guaranteed operation over a wide supply range with  $V_{SS}$  from -4.5 V to -16.5 V and  $V_{DD}$  from +8 V to +16.5 V. The output amplifier headroom requirement is 1.4 V operating with a load current of 1 mA.

The AD5360/AD5361 has a high-speed 4-wire serial interface, which is compatible with SPI®, QSPI™, MICROWIRE™, and DSP interface standards and can handle clock speeds of up to 50 MHz. All the outputs can be updated simultaneously by taking the  $\overline{LDAC}$  input low. Each channel has a programmable gain and an offset adjust register.

Each DAC output is amplified and buffered on-chip with respect to an external SIGGND input. The DAC outputs can also be switched to SIGGND via the CLR pin.

**Table 1. High Channel Count Bipolar DACs**

Model	Resolution	Nominal Output Span	Output Channels	Linearity Error (LSB)	Package Description	Package Option
AD5360BCPZ	16 Bits	4 × VREF (20 V)	16	±4	56-Lead LFCSP	CP-56
AD5360BSTZ	16 Bits	4 × VREF (20 V)	16	±4	52-Lead LQFP	ST-52
AD5361BCPZ	14 Bits	4 × VREF (20 V)	16	±1	56-Lead LFCSP	CP-56
AD5361BSTZ	14 Bits	4 × VREF (20 V)	16	±1	52-Lead LQFP	ST-52
AD5362BCPZ	16 Bits	4 × VREF (20 V)	8	±4	56-Lead LFCSP	CP-56
AD5362BSTZ	16 Bits	4 × VREF (20 V)	8	±4	52-Lead LQFP	ST-52
AD5363BCPZ	14 Bits	4 × VREF (20 V)	8	±1	56-Lead LFCSP	CP-56
AD5363BSTZ	14 Bits	4 × VREF (20 V)	8	±1	52-Lead LQFP	ST-52
AD5370BCPZ	16 Bits	4 × VREF (12 V)	40	±4	64-Lead LFCSP	CP-64
AD5370BSTZ	16 Bits	4 × VREF (12 V)	40	±4	64-Lead LQFP	ST-64
AD5371BCPZ	14 Bits	4 × VREF (12 V)	40	±2	100-Ball CSPBGA	BC-100-2
AD5371BSTZ	14 Bits	4 × VREF (12 V)	40	±2	80-Lead LQFP	ST-80
AD5372BCPZ	16 Bits	4 × VREF (12 V)	32	±4	56-Lead LFCSP	CP-56
AD5372BSTZ	16 Bits	4 × VREF (12 V)	32	±4	64-Lead LQFP	ST-64
AD5373BCPZ	14 Bits	4 × VREF (12 V)	32	±2	56-Lead LFCSP	CP-56
AD5373BSTZ	14 Bits	4 × VREF (12 V)	32	±2	64-Lead LQFP	ST-64

## SPECIFICATIONS

$DV_{CC} = 2.3\text{ V to }5.5\text{ V}$ ;  $V_{DD} = 11.4\text{ V to }16.5\text{ V}$ ;  $V_{SS} = -11.4\text{ V to }-16.5\text{ V}$ ;  $V_{REF} = 5\text{ V}$ ;  $AGND = DGND = SIGGND = 0\text{ V}$ ;  $R_L = \text{Open Circuit}$ ; Gain (m), Offset(c) and DAC Offset registers at default value; all specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.;

**Table 2. Performance Specifications**

Parameter	B Version <sup>1</sup>	Unit	Test Conditions/Comments <sup>1</sup>
<b>ACCURACY</b>			
Resolution	16	Bits	AD5360
	14	Bits	AD5361
Relative Accuracy	$\pm 4$	LSB max	AD5360
	$\pm 1$	LSB max	AD5361
Differential Nonlinearity	$\pm 1$	LSB max	Guaranteed monotonic by design over temperature.
Offset Error	$\pm 20$	mV max	Prior to calibration
Gain Error	$\pm 20$	mV max	Prior to calibration
Offset Error <sup>2</sup>	100	$\mu\text{V}$ max	After calibration
Gain Error <sup>2</sup>	100	$\mu\text{V}$ max	After calibration
Gain Error of Offset DAC	$\pm 35$	mV max	Positive or Negative Full Scale. See Offset DACS section for details
VOUT Temperature Coefficient	5	ppm FSR/ $^{\circ}\text{C}$ typ	Includes linearity, offset, and gain drift.
DC Crosstalk <sup>1</sup>	0.5	mV max	Typically 100 $\mu\text{V}$ . Measured channel at mid-scale, full-scale change on any other channel
<b>REFERENCE INPUTS (VREF0, VREF1)<sup>1</sup></b>			
VREF DC Input Impedance	1	M $\Omega$ min	Typically 100 M $\Omega$ .
VREF Input Current	60	nA max	Per input. Typically $\pm 30$ nA.
VREF Range <sup>4</sup>	2/5	V min/max	$\pm 2\%$ for specified operation.
<b>SIGGND INPUT (SIGGND0, TO SIGGND1)<sup>1</sup></b>			
DC Input Impedance	55	k $\Omega$ min	Typically 60 k $\Omega$ .
Input Range	$\pm 0.5$	V min/max	
<b>OUTPUT CHARACTERISTICS<sup>1</sup></b>			
Output Voltage Range	$V_{SS} + 1.4$ $V_{DD} - 1.4$	V min V max	$I_{LOAD} = 1\text{ mA}$ . $I_{LOAD} = 1\text{ mA}$ .
Nominal Output Voltage Range	-10 to +10	V	
Short Circuit Current	10	mA max	
Load Current	$\pm 1$	mA max	
Capacitive Load	2200	pF max	
DC Output Impedance	0.5	$\Omega$ max	
<b>MONITOR PIN (MON_OUT)</b>			
Output Impedance	500	$\Omega$ typ	
Three State Leakage Current	100	nA typ	
Continuous Current Limit	2	mA max	
<b>DIGITAL INPUTS</b>			
Input High Voltage	1.7	V min	JEDEC compliant. $DV_{CC} = 2.3\text{ V to }3.6\text{ V}$ .
	2.0	V min	$DV_{CC} = 3.6\text{ V to }5.5\text{ V}$ .
Input Low Voltage	0.8	V max	$DV_{CC} = 2.5\text{ V to }5.5\text{ V}$ .
	0.7	V	$DV_{CC} = 2.3\text{ V to }2.7\text{ V}$ .
Input Current	$\pm 1$	$\mu\text{A}$ max	All other digital input pins.
Input Capacitance <sup>1</sup>	10	pF max	
<b>DIGITAL OUTPUTS (SDO, BUSY, GPIO, PEC)</b>			
Output Low Voltage	0.5	V max	Sinking 200 $\mu\text{A}$ .
Output High Voltage (SDO)	$DV_{CC} - 0.5$	V min	Sourcing 200 $\mu\text{A}$ .
High Impedance Leakage Current	$\pm 5$	$\mu\text{A}$ max	SDO only.
High Impedance Output Capacitance	10	pF typ	

Parameter	B Version <sup>1</sup>	Unit	Test Conditions/Comments <sup>1</sup>
TEMPERATURE SENSOR (TMP_OUT)			
Accuracy	±1	°C	@25 °C
	±5	°C max	-40 °C < T < +85°C
Output Voltage at 25 °C	1.5	V typ	
Output Voltage Scale Factor	5	mV/°C typ	
Output Voltage Range	0/3	V min/max	
Output Load Current	200	µA max	Current source only.
Power On Time	10	ms typ	To within ±5 °C
POWER REQUIREMENTS			
DV <sub>CC</sub>	2.3/5.5	V min/max	
V <sub>DD</sub>	8/16.5	V min/max	
V <sub>SS</sub>	-4.5/-16.5	V min/max	
Power Supply Sensitivity <sup>1</sup>			
Δ Full Scale/Δ V <sub>DD</sub>	-75	dB typ	
Δ Full Scale/Δ V <sub>SS</sub>	-75	dB typ	
Δ Full Scale/Δ V <sub>CC</sub>	-90	dB typ	
DI <sub>CC</sub>	2	mA max	V <sub>CC</sub> = 5.5 V, V <sub>IH</sub> = V <sub>CC</sub> , V <sub>IL</sub> = GND.
I <sub>DD</sub>	7	mA max	Outputs unloaded.
I <sub>SS</sub>	7	mA max	Outputs unloaded.
Power Dissipation			
Power Dissipation Unloaded (P)	173	mW	V <sub>SS</sub> = -12 V, V <sub>DD</sub> = +12 V, DV <sub>CC</sub> = 2.5 V
Junction Temperature	130	°C max	T <sub>J</sub> = T <sub>A</sub> + P <sub>TOTAL</sub> × θ <sub>J</sub> <sup>3</sup>

<sup>1</sup> Temperature range for B Version: -40°C to +85°C. Typical specifications are at 25°C.

<sup>2</sup> Guaranteed by design and characterization, not production tested.

<sup>3</sup> Where θ<sub>J</sub> represents the package thermal impedance.

<sup>4</sup> Specifications are guaranteed for a 5V reference only.

## AC CHARACTERISTICS

DV<sub>CC</sub> = 2.5 V; V<sub>DD</sub> = 15 V; V<sub>SS</sub> = -15 V; VREF = 5 V; AGND = DGND = SIGGND = 0 V; R<sub>L</sub> = 10 kΩ to GND; C<sub>L</sub> = 200 pF to GND; Gain (m), Offset(c) and DAC Offset registers at default values; all specifications T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted.

Table 3. AC Characteristics

Parameter	B Version <sup>1,2</sup>	Unit	Test Conditions/Comments
DYNAMIC PERFORMANCE			
Output Voltage Settling Time	TBD	µs typ	Full-scale change
	30	µs max	DAC latch contents alternately loaded with all 0s and all 1s.
Slew Rate	1	V/µs typ	
Digital-to-Analog Glitch Energy	20	nV-s typ	
Glitch Impulse Peak Amplitude	10	mV max	
Channel-to-Channel Isolation	100	dB typ	
DAC-to-DAC Crosstalk	40	nV-s typ	Between DACs inside a group.
	10	nV-s typ	Between DACs from different groups.
Digital Crosstalk	0.1	nV-s typ	
Digital Feedthrough	1	nV-s typ	Effect of input bus activity on DAC output under test.
Output Noise Spectral Density @ 10 kHz	250	nV/(Hz) <sup>1/2</sup> typ	VREF = 0 V.

<sup>1</sup> Temperature range for B Version: -40°C to +85°C. Typical specifications are at 25°C.

<sup>2</sup> Guaranteed by design and characterization, not production tested.

## TIMING CHARACTERISTICS

DV<sub>CC</sub> = 2.3 V to 5.5 V; V<sub>DD</sub> = 8 V to 16.5 V; V<sub>SS</sub> = -4.5 V to -16.5 V; V<sub>REF</sub> = 5 V; AGND = DGND = SIGGND = 0 V; R<sub>L</sub> = Open Circuit; Gain (m), Offset(c) and DAC Offset registers at default value; all specifications T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted.

## SPI INTERFACE (Figure 4 and Figure 5)

Parameter <sup>1, 2, 3</sup>	Limit at T <sub>MIN</sub> , T <sub>MAX</sub>	Unit	Description
t <sub>1</sub>	20	ns min	SCLK Cycle Time.
t <sub>2</sub>	8	ns min	SCLK High Time.
t <sub>3</sub>	8	ns min	SCLK Low Time.
t <sub>4</sub>	11	ns min	$\overline{\text{SYNC}}$ Falling Edge to SCLK Falling Edge Setup Time.
t <sub>5</sub>	20	ns min	Minimum $\overline{\text{SYNC}}$ High Time.
t <sub>6</sub>	10	ns min	24th SCLK Falling Edge to $\overline{\text{SYNC}}$ Rising Edge.
t <sub>7</sub>	5	ns min	Data Setup Time.
t <sub>8</sub>	5	ns min	Data Hold Time.
t <sub>9</sub> <sup>3</sup>	42	ns max	$\overline{\text{SYNC}}$ Rising Edge to $\overline{\text{BUSY}}$ Falling Edge.
t <sub>10</sub>	1.25	$\mu\text{s}$ max	$\overline{\text{BUSY}}$ Pulse Width Low (Single-Channel Update.) See Table 7.
t <sub>11</sub>	500	ns max	Single-Channel Update Cycle Time
t <sub>12</sub>	20	ns min	24th SCLK Falling Edge to $\overline{\text{LDAC}}$ Falling Edge.
t <sub>13</sub>	10	ns min	$\overline{\text{LDAC}}$ Pulse Width Low.
t <sub>14</sub>	3	$\mu\text{s}$ max	$\overline{\text{BUSY}}$ Rising Edge to DAC Output Response Time.
t <sub>15</sub>	0	ns min	$\overline{\text{BUSY}}$ Rising Edge to $\overline{\text{LDAC}}$ Falling Edge.
t <sub>16</sub>	3	$\mu\text{s}$ max	$\overline{\text{LDAC}}$ Falling Edge to DAC Output Response Time.
t <sub>17</sub>	20/30	$\mu\text{s}$ typ/max	DAC Output Settling Time.
t <sub>18</sub>	125	ns max	$\overline{\text{CLR/RESET}}$ Pulse Activation Time.
t <sub>19</sub>	30	ns min	$\overline{\text{RESET}}$ Pulse Width Low.
t <sub>20</sub>	400	$\mu\text{s}$ max	$\overline{\text{RESET}}$ Time Indicated by $\overline{\text{BUSY}}$ Low.
t <sub>21</sub>	270	ns min	Minimum $\overline{\text{SYNC}}$ High Time in Readback Mode.
t <sub>22</sub> <sup>5</sup>	25	ns max	SCLK Rising Edge to SDO Valid.

<sup>1</sup> Guaranteed by design and characterization, not production tested.

<sup>2</sup> All input signals are specified with t<sub>r</sub> = t<sub>f</sub> = 2 ns (10% to 90% of V<sub>CC</sub>) and timed from a voltage level of 1.2 V.

<sup>3</sup> See Figure 4 and Figure 5.

<sup>4</sup> This is measured with the load circuit of Figure 2.

<sup>5</sup> This is measured with the load circuit of Figure 3.

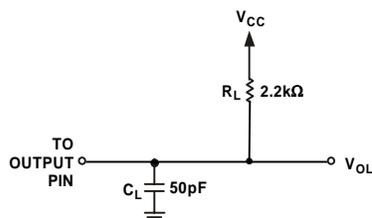


Figure 2. Load Circuit for  $\overline{\text{BUSY}}$  Timing Diagram

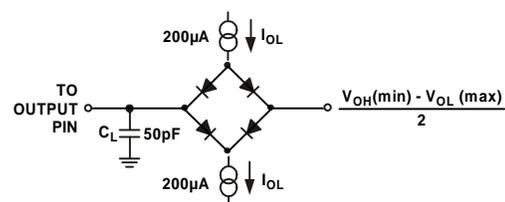
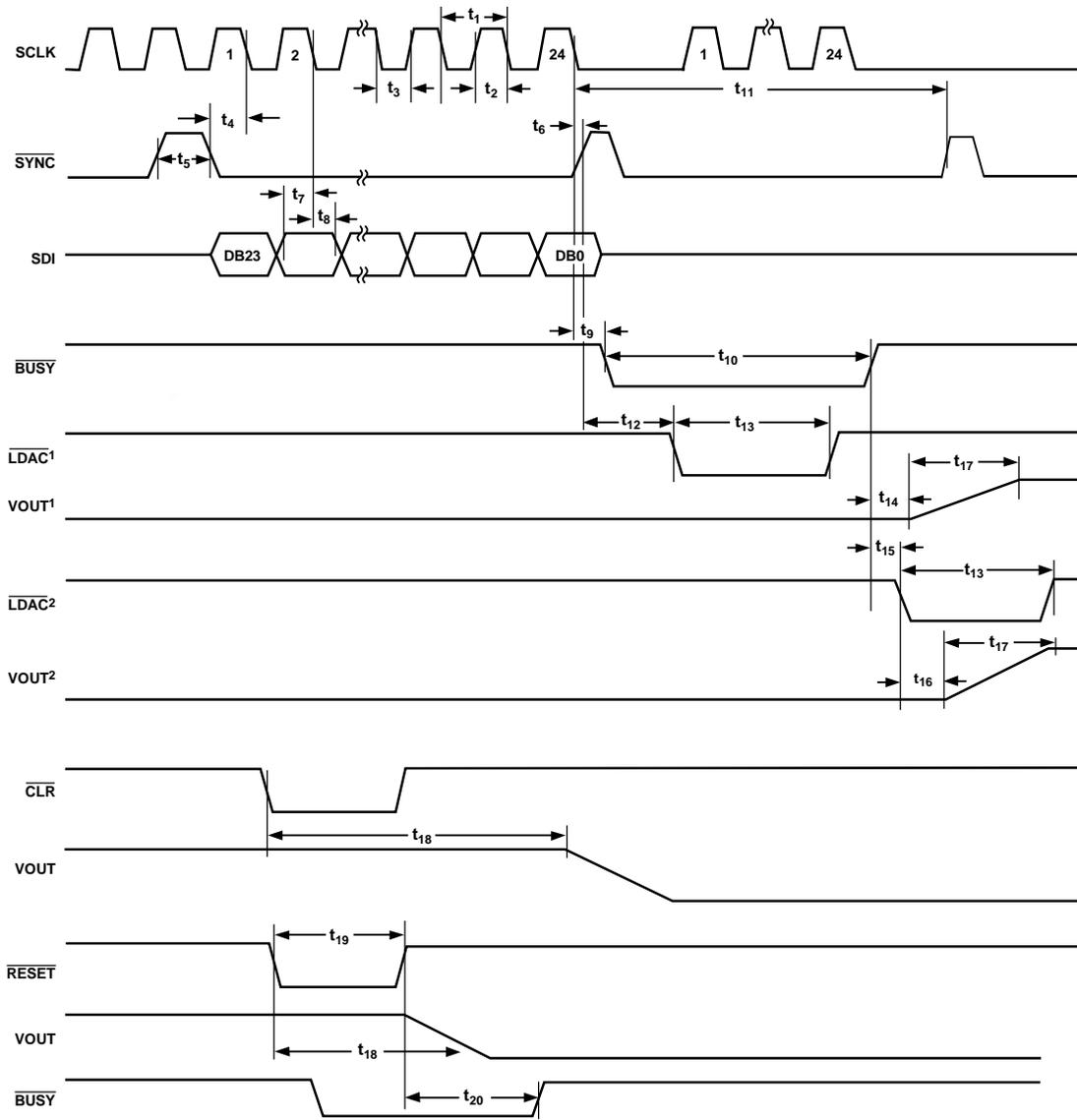


Figure 3. Load Circuit for SDO Timing Diagram



<sup>1</sup>LDAC ACTIVE DURING BUSY.  
<sup>2</sup>LDAC ACTIVE AFTER BUSY.

Figure 4. SPI Write Timing

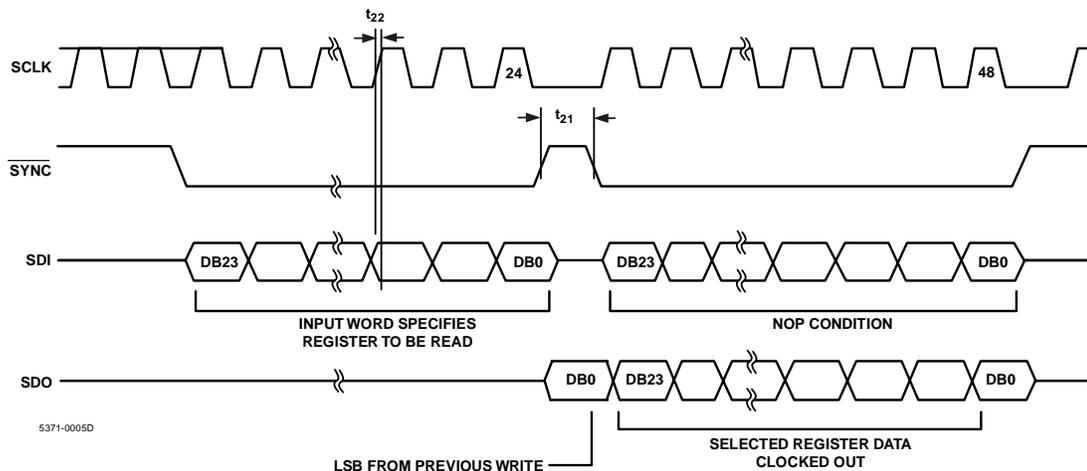


Figure 5. SPI Read Timing

## ABSOLUTE MAXIMUM RATINGS

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

Transient currents of up to 100 mA do not cause SCR latch-up.

**Table 4. Absolute Maximum Ratings**

Parameter	Rating
$V_{DD}$ to AGND	-0.3 V to +17 V
$V_{SS}$ to AGND	-17 V to +0.3 V
$DV_{CC}$ to DGND	-0.3 V to +7 V
Digital Inputs to DGND	-0.3 V to $V_{CC} + 0.3$ V
Digital Outputs to DGND	-0.3 V to $V_{CC} + 0.3$ V
VREF0, VREF1 to AGND	-0.3 V to +5.5 V
VOUT0-VOUT15 to AGND	$V_{SS} - 0.3$ V to $V_{DD} + 0.3$ V
SIGGND to AGND	$\pm 1$ V
AGND to DGND	-0.3 V to +0.3 V
Operating Temperature Range ( $T_A$ )	
Industrial (B Version)	-40°C to +85°C
Storage Temperature Range	-65°C to +150°C
Junction Temperature ( $T_J$ max)	150°C
Reflow Soldering	
Peak Temperature	230°C
Time at Peak Temperature	10 s to 40 s

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only, and 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

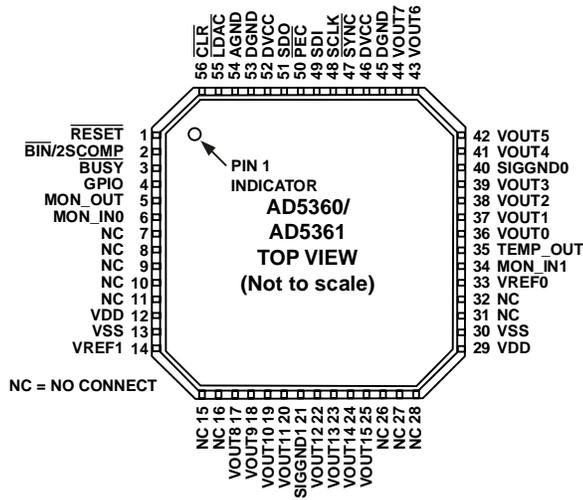


Figure 6. 56 Lead LFCSP Pin Configuration

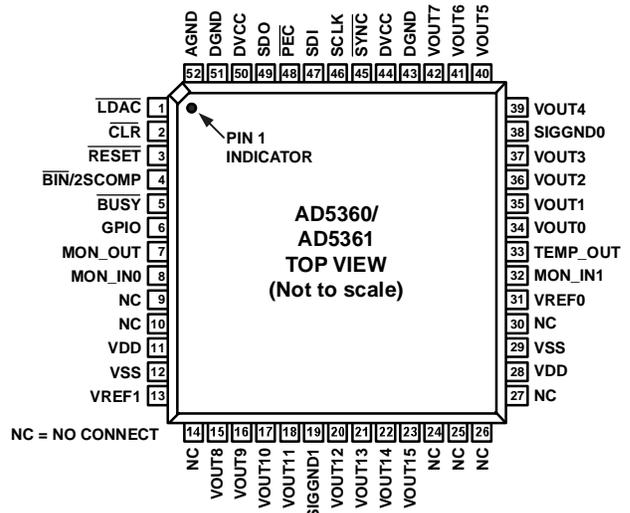


Figure 7. 52 Lead LQFP Pin Configuration

Table 5. Pin Function Descriptions

Pin Name	Function
DV <sub>CC</sub>	Logic Power Supply; 2.3 V to 5.5 V. These pins should be decoupled with 0.1 μF ceramic capacitors and 10 μF capacitors.
V <sub>SS</sub>	Negative Analog Power Supply; -11.4 V to -16.5 V for specified performance. These pins should be decoupled with 0.1 μF ceramic capacitors and 10 μF capacitors.
V <sub>DD</sub>	Positive Analog Power Supply; +11.4 V to +16.5 V for specified performance. These pins should be decoupled with 0.1 μF ceramic capacitors and 10 μF capacitors.
AGND	Ground for All Analog Circuitry. All AGND pins should be connected to the AGND plane.
DGND	Ground for All Digital Circuitry. All DGND pins should be connected to the DGND plane.
SIGGND0	Reference Ground for DACs 0 to 7. VOUT0 to VOUT7 are referenced to this voltage.
SIGGND1	Reference Ground for DACs 8 to 15. VOUT8 to VOUT15 are referenced to this voltage.
VREF0	Reference Input for DACs 0 to 7. This voltage is referred to AGND.
VREF1	Reference Input for DACs 8 to 15. This voltage is referred to AGND.
VOUT0 to VOUT15	DAC Outputs. Buffered analog outputs for each of the 16 DAC channels. Each analog output is capable of driving an output load of 10 kΩ to ground. Typical output impedance of these amplifiers is 0.5 Ω.
SYNC	Active Low or SYNC Input for SPI Interface. This is the frame synchronization signal for the SPI serial interface. See SPI timing diagrams and descriptions for more details.
SCLK	Serial Clock Input for SPI Interface. See SPI timing diagrams and descriptions for more details.
SDI	Serial Data Input for SPI Interface. See SPI timing diagrams and descriptions for more details.
SDO	Serial Data Output for SPI Interface. See SPI timing diagrams and descriptions for more details.
LDAC	Load DAC Logic Input (Active Low). See the BUSY AND LDAC FUNCTIONS section for more information.
BUSY	Digital Input/Open-Drain Output. BUSY is open-drain when an output. See the BUSY AND LDAC FUNCTIONS section for more information.
RESET	Asynchronous Digital Reset Input
CLR	Asynchronous clear input (level sensitive, active low). See the Clear Function section for more information.
PEC	Packet Error Check output. This is an open-drain output with a 50 kΩ pullup, that goes low if the packet error check fails.
TEMP_OUT	Provides an output voltage proportional to chip temperature. This is typically 1.5 V at 25 C with an output variation of 5 mV/C.
MON_OUT	Analog multiplexer output. Any DAC output or the MON_IN0 or the MON_IN1 input can be switched to this output.
MON_IN0, MON_IN1	Analog multiplexer inputs, which can be switched to MON_OUT.

<b>Pin Name</b>	<b>Function</b>
GPIO	Digital I/O pin. This pin can be configured as an input or output that can be read or programmed high or low via the serial interface. When configured as an input it has a weak pulldown.
BIN/2SCOMP	Digital input, sets the DAC coding. 0 = offset binary, 1 = 2's complement. This input has a weak pulldown.
EXPOSED PADDLE	The Lead Free Chip Scale Package (LFCSP) has an exposed paddle on the underside. This should be connected to $V_{SS}$

## TERMINOLOGY

### Relative Accuracy

Relative accuracy, or endpoint linearity, is a measure of the maximum deviation from a straight line passing through the endpoints of the DAC transfer function. It is measured after adjusting for zero-scale error and full-scale error and is expressed in least significant bits (LSB).

### Differential Nonlinearity

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.

### Zero-Scale Error

Zero-scale error is the error in the DAC output voltage when all 0s are loaded into the DAC register.

Zero-scale error is a measure of the difference between VOUT (actual) and VOUT (ideal) expressed in mV. Zero-scale error is mainly due to offsets in the output amplifier.

### Full-Scale Error

Full-scale error is the error in DAC output voltage when all 1s are loaded into the DAC register.

Full-scale error is a measure of the difference between VOUT (actual) and VOUT (ideal) expressed in mV. It does not include zero-scale error.

**Gain Error** Gain error is the difference between full-scale error and zero-scale error. It is expressed in mV.

$$\text{Gain Error} = \text{Full-Scale Error} - \text{Zero-Scale Error}$$

### VOUT Temperature Coefficient

This includes output error contributions from linearity, offset, and gain drift.

### DC Output Impedance

DC output impedance is the effective output source resistance. It is dominated by package lead resistance.

### DC Crosstalk

The DAC outputs are buffered by op amps that share common  $V_{DD}$  and  $V_{SS}$  power supplies. If the dc load current changes in one channel (due to an update), this can result in a further dc change in one or more channel outputs. This effect is more significant at high load currents and reduces as the load currents are reduced. With high impedance loads, the effect is virtually immeasurable. Multiple  $V_{DD}$  and  $V_{SS}$  terminals are provided to minimize dc crosstalk.

### Output Voltage Settling Time

The amount of time it takes for the output of a DAC to settle to a specified level for a full-scale input change.

### Digital-to-Analog Glitch Energy

The amount of energy injected into the analog output at the major code transition. It is specified as the area of the glitch in nV-s. It is measured by toggling the DAC register data between 0x1FFF and 0x2000.

### Channel-to-Channel Isolation

Channel-to-channel isolation refers to the proportion of input signal from one DAC's reference input that appears at the output of another DAC operating from another reference. It is expressed in dB and measured at midscale.

### DAC-to-DAC Crosstalk

DAC-to-DAC crosstalk is the glitch impulse that appears at the output of one converter due to both the digital change and subsequent analog output change at another converter. It is specified in nV-s.

### Digital Crosstalk

The glitch impulse transferred to the output of one converter due to a change in the DAC register code of another converter is defined as the digital crosstalk and is specified in nV-s.

### Digital Feedthrough

When the device is not selected, high frequency logic activity on the device's digital inputs can be capacitively coupled both across and through the device to show up as noise on the VOUT pins. It can also be coupled along the supply and ground lines. This noise is digital feedthrough.

### Output Noise Spectral Density

Output noise spectral density is a measure of internally generated random noise. Random noise is characterized as a spectral density (voltage per  $\sqrt{\text{Hz}}$ ). It is measured by loading all DACs to midscale and measuring noise at the output. It is measured in  $\text{nV}/(\text{Hz})^{1/2}$ .

## FUNCTIONAL DESCRIPTION

### DAC ARCHITECTURE—GENERAL

The AD5360/AD5361 contains 16 DAC channels and 16 output amplifiers in a single package. The architecture of a single DAC channel consists of a 16-bit resistor-string DAC in the case of the AD5360 and a 14-bit DAC in the case of the AD5361, followed by an output buffer amplifier. The resistor-string section is simply a string of resistors, each of value R, from VREF to AGND. This type of architecture guarantees DAC monotonicity. The 16(14)-bit binary digital code loaded to the DAC register determines at which node on the string the

voltage is tapped off before being fed into the output amplifier. The output amplifier multiplies the DAC out voltage by 4. The output span is 12 V with a 3 V reference and 20 V with a 5 V reference.

### CHANNEL GROUPS

The 16 DAC channels of the AD5360/AD5361 are arranged into two groups of 8 channels. The eight DACs of Group 0 derive their reference voltage from VREF0, and those of Group 1 from VREF1.

**Table 6. AD5360(AD5361) Registers**

Register Name	Word Length (Bits)	Description
X1A (group)(channel)	16(14)	Input data register A, one for each DAC channel.
X1B (group) (channel)	16(14)	Input data register B, one for each DAC channel.
M (group) (channel)	16(14)	Gain trim registers, one for each DAC channel.
C (group) (channel)	16(14)	Offset trim registers, one for each DAC channel.
X2A (group)(channel)	16(14)	Output data register A, one for each DAC channel. These registers store the final, calibrated DAC data after gain and offset trimming. They are not readable, nor directly writable.
X2B (group) (channel)	16(14)	Output data register B, one for each DAC channel. These registers store the final, calibrated DAC data after gain and offset trimming. They are not readable, nor directly writable.
DAC (group) (channel)		Data registers from which the DACs take their final input data. The DAC registers are updated from the X2A or X2B registers. They are not readable, nor directly writable.
OFS0	14	Offset DAC 0 data register, sets offset for Group 0.
OFS1	14	Offset DAC 1 data register, sets offset for Group 1.
Control	8	Bit 4 = Overtemperature indicator. 1 = chip temperature > 130 °C. Bit 3 = PEC error flag. 1 = PEC error. Cleared on reading control register. Bit 2 = $\bar{A}/B$ . 0 = global selection of X1A input data registers. 1 = X1B registers. Bit 1 = Enable Temp Shutdown. 0 = disable temp shutdown. 1 = enable. Bit 0 = Soft Power Down. 0 = soft power up. 1 = soft power down.
Monitor	6	Bit 5 = Monitor enable. 0 = off. 1 = on. Bit 4 = 0, DAC selected by bits 3 to 0. Bits 3 – 0 = DAC channel 0000 = 0 to 1111 = 15. Bit 4 = 1, MON_IN pin selected by bit 0. Bit 0 = MON_IN select. 0 = MON_IN0. 1 = MON_IN1.
GPIO	2	Bit 1 = GPIO configuration. 0 = input. 1 = output. Bit 0 = GPIO data. Stores state of GPIO pin when input. Drives GPIO pin when output.

### A/ B REGISTERS GAIN/OFFSET ADJUSTMENT

Each DAC channel has seven data registers. The actual DAC data word can be written to either the X1A or X1B input register, depending on the setting of the  $\overline{A/B}$  bit in the Control Register. If the  $\overline{A/B}$  bit is 0, data will be written to the X1A register. If the  $\overline{A/B}$  bit is 1, data will be written to the X1B register. Note that this single bit is a global control and affects every DAC channel in the device. It is not possible to set up the device on a per-channel basis so that some writes are to X1A registers and some writes are to X1B registers.

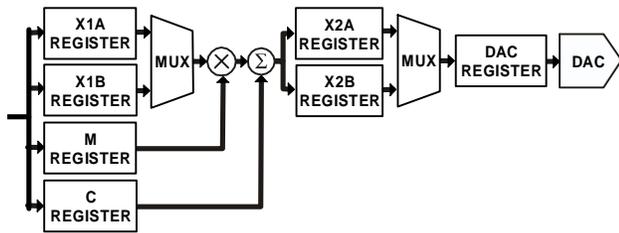


Figure 8 Data Registers Associated With Each DAC Channel

Each DAC channel also has a gain (M) and offset (C) register, which allow trimming out of the gain and offset errors of the entire signal chain. Data from the X1A register is operated on by a digital multiplier and adder controlled by the contents of the M and C registers. The calibrated DAC data is then stored in the X2A register. Similarly, data from the X1B register is operated on by the multiplier and adder and stored in the X2B register.

Although a multiplier and adder symbol are shown for each channel, there is only one multiplier and one adder in the device, which are shared between all channels. This has implications for the update speed when several channels are updated at once, as described later.

Each time data is written to the X1A register, or to the M or C register with the  $\overline{A/B}$  control bit set to 0, the X2A data is recalculated and the X2A register is automatically updated. Similarly, X2B is updated each time data is written to X1B, or to M or C with  $\overline{A/B}$  set to 1. The X2A and X2B registers are not readable, nor directly writable by the user.

Data output from the X2A and X2B registers is routed to the final DAC register by a multiplexer. Whether each individual DAC takes its data from the X2A or X2B register is controlled by an 8-bit A/B Select Register associated with each group of 8 DACs. If a bit in this register is 0, the DAC takes its data from the X2A register; if 1 the DAC takes its data from the X2B register (bit 0 controls DAC 0 through bit 7 controls DAC 7).

Note that, since there are 16 bits in 2 registers, it is possible to set up, on a per-channel basis, whether each DAC takes its data from the X2A or X2B register. A global command is also provided that sets all bits in the A/B Select Registers to 0 or to 1.

All DACs in the AD5360/AD5361 can be updated simultaneously by taking  $\overline{LDAC}$  low, when each DAC register will be updated from either its X2A or X2B register, depending on the setting of the A/B select registers. The DAC register is not readable, nor directly writable by the user.

### OFFSET DACS

In addition to the gain and offset trim for each DAC, there are two 14-bit Offset DACs, one for Group 0, and one for Group 1. These allow the output range of all DACs connected to them to be offset within a defined range. Thus, subject to the limitations of headroom, it is possible to set the output range of Group 0, and/or Group 1 to be unipolar positive, unipolar negative, or bipolar, either symmetrical or asymmetrical about zero volts. The DACs in the AD5360/AD5361 are factory trimmed with the Offset DACs set at their default values. This gives the best offset and gain performance for the default output range and span.

When the output range is adjusted by changing the value of the Offset DAC an extra offset is introduced due to the gain error of the Offset DAC. The amount of offset is dependent on the magnitude of the reference and how much the Offset DAC moves from its default value. This offset is quoted on the specification page. The worst case offset occurs when the Offset DAC is at positive or negative full-scale. This value can be added to the offset present in the main DAC of a channel to give an indication of the overall offset for that channel. In most cases the offset can be removed by programming the channels C register with an appropriate value. The extra offset cause by the Offset DACs only needs to be taken into account when the Offset DAC is changed from its default value. Figure 9 shows the allowable code range which may be loaded to the Offset DAC and this is dependant on the reference value used. Thus, for a 5V reference, the Offset DAC should not be programmed with a value greater than 8192 (0x2000).

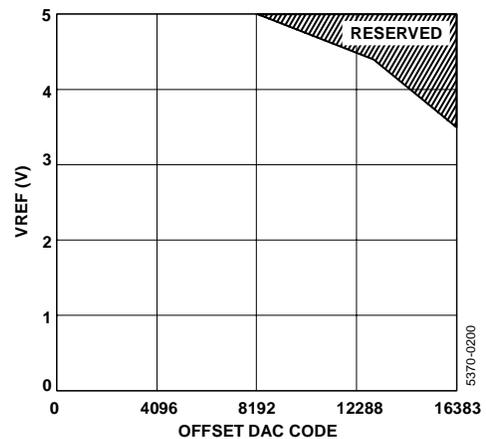


Figure 9. Offset DAC Code Range

## OUTPUT AMPLIFIER

As the output amplifiers can swing to 1.4 V below the positive supply and 1.4 V above the negative supply, this limits how much the output can be offset for a given reference voltage. For example, it is not possible to have a unipolar output range of 20V, since the maximum supply voltage is  $\pm 16.5$  V.

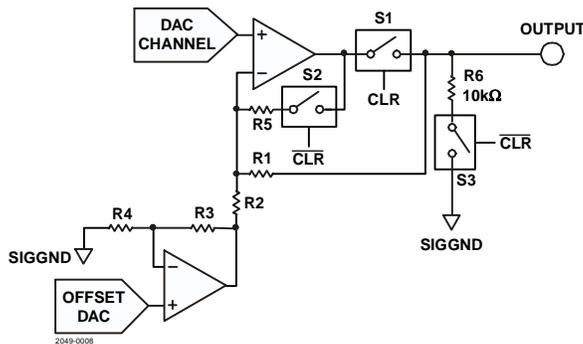


Figure 10. Output Amplifier and Offset DAC

Figure 10 shows details of a DAC output amplifier and its connections to the Offset DAC. On power up, S1 is open, disconnecting the amplifier from the output. S3 is closed, so the output is pulled to SIGGND. S2 is also closed to prevent the output amplifier being open-loop. If  $\overline{\text{CLR}}$  is low at power-up, the output will remain in this condition until  $\overline{\text{CLR}}$  is taken high. The DAC registers can be programmed, and the outputs will assume the programmed values when  $\overline{\text{CLR}}$  is taken high. Even if  $\overline{\text{CLR}}$  is high at power-up, the output will remain in the above condition until  $V_{\text{DD}} > 6$  V and  $V_{\text{SS}} < -4$  V and the initialization sequence has finished. The outputs will then go to their power-on default value.

## TRANSFER FUNCTION

From the foregoing, it can be seen that the output voltage of a DAC in the AD5360/AD5361 depends on the value in the input register, the value of the M and C registers, and the offset from the Offset DAC.

The transfer function is given by:

### AD5360

Code applied to DAC from X1A or X1B register:-

$$\text{DAC\_CODE} = \text{INPUT\_CODE} \times (m+1)/2^{16} + c - 2^{15}$$

DAC output voltage:-

$$V_{\text{OUT}} = 4 \times V_{\text{REF}} \times (\text{DAC\_CODE} - \text{OFFSET\_CODE} \times 4) / 2^{16} + V_{\text{SIGGND}}$$

Notes

DAC\_CODE should be within the range of 0 to 65535

For 12 V span  $V_{\text{REF}} = 3.0$  V.

For 20 V span  $V_{\text{REF}} = 5.0$  V.

X1A, X1B default code = 32768

m = code in gain register; default m code =  $2^{16} - 1$ .

c = code in offset register; default m code =  $2^{15}$ .

OFFSET\_CODE is the 14-bit code written to the offset DAC register. As this DAC is a 14 bit device, the code is multiplied by 4 to make the transfer function correct, since the X, M and C registers are 16-bit. The default value for the Offset DAC is 8192 (0x2000)

### AD5361

Code applied to DAC from X1A or X1B register:-

$$\text{DAC\_CODE} = \text{INPUT\_CODE} \times (m+1)/2^{14} + c - 2^{13}$$

DAC output voltage:-

$$V_{\text{OUT}} = 4 \times V_{\text{REF}} \times (\text{DAC\_CODE} - \text{OFFSET\_CODE}) / 2^{14} + V_{\text{SIGGND}}$$

Notes

DAC\_CODE should be within the range of 0 to 16383

For 12 V span  $V_{\text{REF}} = 3.0$  V.

For 20 V span  $V_{\text{REF}} = 5.0$  V.

X1A, X1B default code = 8192

m = code in gain register; default m code =  $2^{14} - 1$ .

c = code in offset register; default m code =  $2^{13}$ .

OFFSET\_CODE is the code loaded to the offset DAC. The default value for the Offset DAC is 8192 (0x2000)

## REFERENCE SELECTION

The AD5360/AD5361 has two reference input pins. The voltage applied to the reference pins determines the output voltage span on VOUT0 to VOUT15.  $V_{\text{REF0}}$  determines the voltage span for VOUT0 to VOUT7 and  $V_{\text{REF1}}$  determines the voltage span for VOUT8 to VOUT15. The reference voltage applied to each VREF pin can be different, if required, allowing each group of 8 channels to have a different voltage span. The output voltage range can be adjusted further by programming the offset and gain registers for each channel as well as programming the offset DAC. If the offset and gain features are not used (i.e. the m and c registers are left at their default values) the required reference levels can be calculated as follows:

$$V_{\text{REF}} = (V_{\text{OUT}_{\text{max}}} - V_{\text{OUT}_{\text{min}}})/4$$

If the offset and gain features of the AD5360/AD5361 are used, then the required output range is slightly different. The chosen output range should take into account the system offset and gain errors that need to be trimmed out. Therefore, the chosen output range should be larger than the actual, required range.

The required reference levels can be calculated as follows:

1. Identify the nominal output range on VOUT.
2. Identify the maximum offset span and the maximum gain required on the full output signal range.
3. Calculate the new maximum output range on VOUT including the expected maximum offset and gain errors.
4. Choose the new required  $V_{\text{OUT}_{\text{max}}}$  and  $V_{\text{OUT}_{\text{min}}}$ , keeping the VOUT limits centered on the nominal

values. Note that  $V_{DD}$  and  $V_{SS}$  must provide sufficient headroom.

5. Calculate the value of  $V_{REF}$  as follows:

$$V_{REF} = (V_{OUTMAX} - V_{OUTMIN})/4$$

### Reference Selection Example

Nominal Output Range = 20V (-10V to +10V)

Offset Error =  $\pm 100\text{mV}$

Gain Error =  $\pm 3\%$

SIGGND = AGND = 0V

- 1) Gain Error =  $\pm 3\%$   
 $\Rightarrow$  Maximum Positive Gain Error =  $+3\%$   
 $\Rightarrow$  Output Range incl. Gain Error =  $20 + 0.03(20) = 20.6\text{V}$
- 2) Offset Error =  $\pm 100\text{mV}$   
 $\Rightarrow$  Maximum Offset Error Span =  $2(100\text{mV}) = 0.2\text{V}$   
 $\Rightarrow$  Output Range including Gain Error and Offset Error =  $20.6\text{V} + 0.2\text{V} = 20.8\text{V}$
- 3)  $V_{REF}$  Calculation  
 Actual Output Range = 20.6V, that is -10.3V to +10.3V (centered);  
 $V_{REF} = (10.3\text{V} + 10.3\text{V})/4 = 5.15\text{V}$

If the solution yields an inconvenient reference level, the user can adopt one of the following approaches:

1. Use a resistor divider to divide down a convenient, higher reference level to the required level.
2. Select a convenient reference level above  $V_{REF}$  and modify the Gain and Offset registers to digitally downsize the reference. In this way the user can use almost any convenient reference level but may reduce the performance by overcompaction of the transfer function.
3. Use a combination of these two approaches

### CALIBRATION

The user can perform a system calibration on the AD5360 and AD5361 to reduce gain and offset errors to below 1 LSB. This is achieved by calculating new values for the M and C registers and reprogramming them.

#### Reducing Zero-scale and Full-scale Error

Zero-scale error can be reduced as follows:

1. Set the output to the lowest possible value.
2. Measure the actual output voltage and compare it with the required value. This gives the zero-scale error.
3. Calculate the number of LSBs equivalent to the error and subtract this from the default value of

the C register. Note that only negative zero-scale error can be reduced.

Full-scale error can be reduced as follows:

1. Measure the zero-scale error.
2. Set the output to the highest possible value.
3. Measure the actual output voltage and compare it with the required value. Add this error to the zero-scale error. This is the full-scale error.
4. Calculate the number of LSBs equivalent to the full-scale error and subtract it from the default value of the M register. Note that only positive full-scale error can be reduced.
5. The M and C registers should not be programmed until both zero-scale and full-scale errors have been calculated.

### AD5360 CALIBRATION EXAMPLE

This example assumes that a -10 V to +10 V output is required. The DAC output is set to -10 V but measured at -10.03 V. This gives a zero-scale error of -30 mV.

1.  $1 \text{ LSB} = 20 \text{ V}/65536 = 305.176 \mu\text{V}$
2.  $30 \text{ mV} = 98 \text{ LSB}$
3. 98 LSB should be added to the default C register value:  
 $(32768 + 98) = 32866$
4. 32866 should be programmed to the C register

The full-scale error can now be removed. The output is set to +10 V and a value of +10.02 V is measured. The full-scale error is  $+20 \text{ mV} - (-30 \text{ mV}) = +50 \text{ mV}$ . This is a full-scale error of +50 mV.

1.  $50 \text{ mV} = 164 \text{ LSBs}$
2. 164 LSB should be subtracted from the default M register value:  $(65535 - 164) = 65371$
3. 65371 should be programmed to the M register

### RESET FUNCTION

When the  $\overline{\text{RESET}}$  pin is taken low, the DAC buffers are disconnected and the DAC outputs VOUT0 to VOUT15 are tied to their associated SIGGND signals via a 10 k $\Omega$  resistor. On the rising edge of  $\overline{\text{RESET}}$  the AD5360/AD5361 state machine initiates a reset sequence to reset the X, M and C registers to their default values. This sequence typically takes 300 $\mu\text{s}$  and the user should not write to the part during this time. When the reset sequence is complete, and provided that CLR is high, the

DAC output will be at a potential specified by the default register settings which will be equivalent to SIGGND. The DAC outputs will remain at SIGGND until the X, M or C registers are updated and  $\overline{\text{LDAC}}$  is taken low.

### CLEAR FUNCTION

$\overline{\text{CLR}}$  is an active low input which should be high for normal operation. The  $\overline{\text{CLR}}$  pin has an internal 500k $\Omega$  pull-down resistor. When  $\overline{\text{CLR}}$  is low, the input to each of the DAC output buffer stages, VOUT0 to VOUT15, is switched to the externally set potential on the relevant SIGGND pin. While  $\overline{\text{CLR}}$  is low, all  $\overline{\text{LDAC}}$  pulses are ignored. When  $\overline{\text{CLR}}$  is taken high again, the DAC outputs remain cleared until  $\overline{\text{LDAC}}$  is taken low. The contents of input registers and DAC registers 0 to 15 are not affected by taking  $\overline{\text{CLR}}$  low. To prevent glitches appearing on the outputs  $\overline{\text{CLR}}$  should be brought low whenever the output span is adjusted by writing to the offset DAC.

### BUSY AND LDAC FUNCTIONS

The value of an X2 (A or B) register is calculated each time the user writes new data to the corresponding X1, C, or M registers. During the calculation of X2, the  $\overline{\text{BUSY}}$  output goes low. While  $\overline{\text{BUSY}}$  is low, the user can new data to the X1, M, or C registers, provided the first stage of the calculation is complete (see the Register Update Rates section for more details).

The  $\overline{\text{BUSY}}$  pin is bidirectional and has a 50 k $\Omega$  internal pullup resistor. Where multiple AD5360 or AD5361 devices may be used in one system the  $\overline{\text{BUSY}}$  pins can be tied together. This is useful where it is required that no DAC in any device is updated until all other DACs are ready. When each device has finished updating the X2 (A or B) registers it will release the  $\overline{\text{BUSY}}$  pin. If another device hasn't finished updating its X2 registers it will hold  $\overline{\text{BUSY}}$  low, thus delaying the effect of  $\overline{\text{LDAC}}$  going low.

The DAC outputs are updated by taking the  $\overline{\text{LDAC}}$  input low. If  $\overline{\text{LDAC}}$  goes low while  $\overline{\text{BUSY}}$  is active, the  $\overline{\text{LDAC}}$  event is stored and the DAC outputs update immediately after  $\overline{\text{BUSY}}$  goes high. A user can also hold the  $\overline{\text{LDAC}}$  input permanently low. In this case, the DAC outputs update immediately after  $\overline{\text{BUSY}}$  goes high.  $\overline{\text{BUSY}}$  also goes low, for approximately 500ns, whenever the A/B Select Registers are written to.

As described later, the AD5360/AD5361 has flexible addressing that allows writing of data to a single channel, all channels in a group, or all channels in the device. This means that several register values may need to be calculated and updated. As there is only one multiplier shared between 16 channels, this task must be done sequentially, so the length of the  $\overline{\text{BUSY}}$  pulse will vary according to the number of channels being updated.

Table 7.  $\overline{\text{BUSY}}$  Pulse Widths

Action	$\overline{\text{BUSY}}$ Pulse Width ( $\mu\text{s max}$ )
Loading X1A, X1B, C, or M to 1 channel	1.25
Loading X1A, X1B, C, or M to 2 channels	1.75
Loading X1A, X1B, C, or M to 8 channels	4.75
Loading X1A, X1B, C, or M to 16 channels	8.75

$$\overline{\text{BUSY}} \text{ Pulse Width} = ((\text{Number of Channels} + 1) \times 500\text{ns}) + 250\text{ns}$$

The AD5360/AD5361 contains an extra feature whereby a DAC register is not updated unless its X2A or X2B register has been written to since the last time  $\overline{\text{LDAC}}$  was brought low. Normally, when  $\overline{\text{LDAC}}$  is brought low, the DAC registers are filled with the contents of the X2A or X2B registers, depending on the setting of the A/B Select Registers. However the AD5360/AD5361 updates the DAC register only if the X2 data has changed, thereby removing unnecessary digital crosstalk.

### $\overline{\text{BIN}}/2\text{SCOMP}$ PIN

The  $\overline{\text{BIN}}/2\text{SCOMP}$  pin determines if the input data is interpreted as offset binary or 2's complement. If this pin is low, then the data is binary. If it is 1, the data is interpreted as 2's complement. This affects only the X, C, and Offset DAC registers. The M register data and all control and command data is interpreted as straight binary.

### TEMPERATURE SENSOR

The on-chip temperature sensor provides a voltage output at the TEMP\_OUT pin that is linearly proportional to the Centigrade temperature scale. The typical accuracy of the temperature sensor is  $\pm 1^\circ\text{C}$  at  $+25^\circ\text{C}$  and  $\pm 5^\circ\text{C}$  over the  $-40^\circ\text{C}$  to  $+85^\circ\text{C}$  range. Its nominal output voltage is 1.5V at  $+25^\circ\text{C}$ , varying at 5 mV/ $^\circ\text{C}$ , giving a typical output range of 1.175V to 1.9 V over the full temperature range. Its low output impedance, low self heating, and linear output simplify interfacing to temperature control circuitry and A/D converters.

## MONITOR FUNCTION

The AD5360/AD5361 contains a channel monitor function that consists of an analog multiplexer addressed via the serial interface, allowing any channel output to be routed to this pin for monitoring using an external ADC. In addition, two monitor inputs, MON\_IN0 and MON\_IN1 are provided, which can also be routed to MON\_OUT. The monitor function is controlled by the Monitor Register, which allows the monitor output to be enabled or disabled, and selection of a DAC channel or one of the monitor pins. When disabled, the monitor output is high impedance, so several monitor outputs may be connected in parallel and only one enabled at a time. Table 8 shows the control register settings relevant to the monitor function.

**Table 8. Control Register Monitor Functions**

F5	F4	F3	F2	F1	F0	
0	X	X	X	X	X	MON_OUT Disabled
1	X	X	X	X	X	MON_OUT Enabled
1	0	0	0	0	X	MON_OUT = VOUT0
1	0	0	0	0	1	MON_OUT = VOUT1
1	0	1	1	1	1	MON_OUT = VOUT15
1	1	0	0	0	0	MON_OUT = MON_IN0
1	1	0	0	0	1	MON_OUT = MON_IN1

The multiplexer is implemented as a series of analog switches. Since this could conceivably cause a large amount of current to flow from the input of the multiplexer, i.e. VOUTx or MON\_INx to the output of the multiplexer, MON\_OUT, care should be taken to ensure that whatever is connected to the MON\_OUT pin is of high enough impedance to prevent the Continuous Current Limit specification from being exceeded.

## GPIO PIN

The AD5360/AD5361 has a general-purpose I/O pin, GPIO. This can be configured as an input or an output and read back or programmed (when configured as an output) via the serial interface. Typical applications for this pin include monitoring the status of a logic signal, limit switch, or controlling an external multiplexer. The GPIO pin is configured by writing to the GPIO register, which has the special function code of 0b001101 (see Table 13 and Table 14). When Bit F1 is set the GPIO pin will be an output and F0 will determine whether the pin is high or low. The GPIO pin can be set as an input by writing 0 to both F1 and F0. The status of the GPIO pin can be determined by initiating a read operation using the appropriate bits in Table 15. The status of the pin will be indicated by the LSB of the register read.

## POWER-DOWN MODE

The AD5360/AD5361 can be powered down by setting Bit 0 in the control register. This will turn off the DACs thus reducing the current consumption. The DAC outputs will be connected to their respective SIGGND potentials. The power-down mode doesn't change the contents of the registers and the DACs will return to their previous voltage when the power-down bit is cleared.

## THERMAL MONITORING FUNCTION

The AD5360/AD5361 can be programmed to power down the DACs if the temperature on the die exceeds 130°C. Setting Bit 1 in the control register (see Table 14) will enable this function. If the die temperature exceeds 130°C the AD5360/AD5361 will enter a temperature power-down mode, which is equivalent to setting the power-down bit in the control register. To indicate that the AD5360/AD5361 has entered temperature shutdown mode Bit 4 of the control register is set. The AD5360/AD5361 will remain in temperature shutdown mode, even if the die temperature falls, until Bit 1 in the control register is cleared.

## TOGGLE MODE

The AD5360/AD5361 has two X2 registers per channel, X2A and X2B, which can be used to switch the DAC output between two levels with ease. This approach greatly reduces the overhead required by a micro-processor which would otherwise have to write to each channel individually. When the user writes to either the X1A, X2A, M or C registers the calculation engine will take a certain amount of time to calculate the appropriate X2A or X2B values. If the application only requires that the DAC output switch between two levels, such as a data generator, any method which reduces the amount of calculation time encountered is advantageous. For the data generator example the user need only set the high and low levels for each channel once, by writing to the X1A and X1B registers. The values of X2A and X2B will be calculated and stored in their respective registers. The calculation delay therefore only happens during the setup phase, i.e. when programming the initial values. To toggle a DAC output between the two levels it is only required to write to the relevant A/B Select Register to set the MUX2 register bit. Furthermore, since there are 8 MUX2 control bits per register it is possible to update eight channels with a single write. Table 16 shows the bits that correspond to each DAC output.

## SERIAL INTERFACE

The AD5360/AD5361 contains an SPI-compatible interface operating at clock frequencies up to 50MHz (20MHz for read operations). To minimize both the power consumption of the device and on-chip digital noise, the interface powers up fully only when the device is being written to, that is, on the falling edge of  $\overline{\text{SYNC}}$ . The serial interface is 2.5 V LVTTTL compatible when operating from a 2.3 V to 3.6 V  $\text{DV}_{\text{CC}}$  supply. It is controlled by four pins, as follows.

### $\overline{\text{SYNC}}$

Frame synchronization input.

### SCLK

Clocks data in and out of the device.

### SDI

Serial data input pin.

### SDO

Serial data output pin

## SPI WRITE MODE

The AD5360/AD5361 allows writing of data via the serial interface to every register directly accessible to the serial interface, which is all registers except the X2A and X2B registers and the DAC registers. The X2A and X2B registers are updated automatically when writing to the X1A, X1B, M and C registers, and the DAC registers are updated by  $\overline{\text{LDAC}}$ .

The serial word (see Table 9 and Table 10) is 24 bits long. 16(14) of these bits are data bits, five bits are address bits, and two bits are mode bits that determine what is done with the data.

The serial interface works with both a continuous and a burst (gated) serial clock. Serial data applied to SDI is clocked into the AD5360/AD5361 by clock pulses applied to SCLK. The first falling edge of  $\overline{\text{SYNC}}$  starts the write cycle. At least 24 falling clock edges must be applied to SCLK to clock in 24 bits of data, before  $\overline{\text{SYNC}}$  is taken high again. If  $\overline{\text{SYNC}}$  is taken high before the 24th falling clock edge, the write operation will be aborted.

If a continuous clock is used, and PEC mode isn't used,  $\overline{\text{SYNC}}$  must be taken high before the 25th falling clock edge. This inhibits the clock within the AD5360/AD5361. If more than 24 falling clock edges are applied before  $\overline{\text{SYNC}}$  is taken high again, the input data will be corrupted. If an externally gated clock of exactly 24 pulses is used,  $\overline{\text{SYNC}}$  may be taken high any time after the 24th falling clock edge.

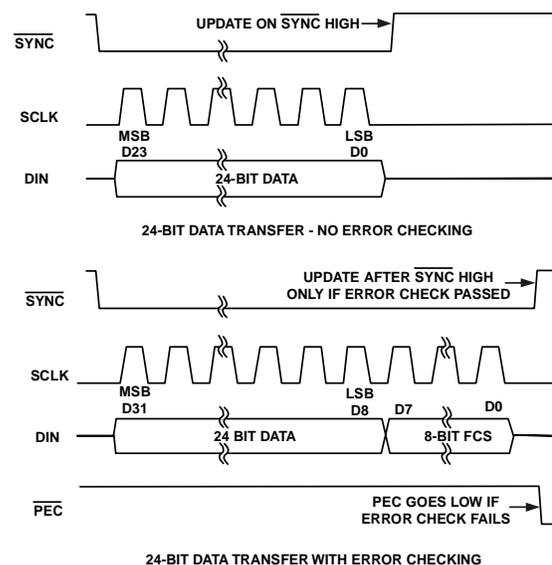
The input register addressed is updated on the rising edge of  $\overline{\text{SYNC}}$ . In order for another serial transfer to take place,  $\overline{\text{SYNC}}$  must be taken low again.

## REGISTER UPDATE RATES

As mentioned previously the value of the X2 (A or B) register is calculated each time the user writes new data to the corresponding X1, C or M registers. The calculation is performed by a three stage process. The first two stages take 500ns each and the third stage takes 250ns. When the write to one of the X1, C or M registers is complete the calculation process begins. If the write operation involves the update of a single DAC channel the user is free to write to another register provided that the write operation doesn't finish until the first stage calculation is complete, i.e. 500ns after the completion of the first write operation. If a group of channels is being updated by a single write operation the first stage calculation will be repeated for each channel, taking 500ns per channel. In this case the user should not complete the next write operation until this time has elapsed.

## PACKET ERROR CHECKING

To verify that data has been received correctly in noisy environments, the AD5360/AD5361 offers the option of error checking based on an 8-bit (CRC-8) cyclic redundancy check. The device controlling the AD5360/AD5361 should generate an 8-bit frame check sequence using the polynomial  $C(x) = x^8 + x^2 + x^1 + 1$ . This is added to the end of the data word, and 32 data bits are sent to the AD5360/AD5361 before taking  $\overline{\text{SYNC}}$  high. If the AD5360/AD5361 sees a 32-bit data frame, it will perform the error check when  $\overline{\text{SYNC}}$  goes high. If the check is valid, then the data will be written to the selected register. If the error check fails, the Packet Error Check output (PEC) will go low and bit 3 of the Control Register is set. After reading this register, this error flag is cleared automatically and  $\overline{\text{PEC}}$  goes high again.



5360-0010

Figure 11. SPI Write With and Without Error Checking

**Table 9. AD5360 Serial Word Bit Assignment**

I23	I22	I21	I20	I19	I18	I17	I16	I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
M1	M0	A5	A4	A3	A2	A1	A0	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0

**Table 10. AD5361 Serial Word Bit Assignment**

I23	I22	I21	I20	I19	I18	I17	I16	I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1*	I0*
M1	M0	A5	A4	A3	A2	A1	A0	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	0	0

M1 and M0 are mode bits.

A5 is an unused address bit and must always be written as 0.

A4 to A0 are address bits.

D15 to D0 are data bits.

\*In the AD5361, bits I1 and I0 only used in Special Function Mode

### SPI READBACK MODE

The AD5360/AD5361 allows data readback via the serial interface from every register directly accessible to the serial interface, which is all registers except the X2A, X2B and DAC registers. In order to read back a register, it is first necessary to tell the AD5360/AD5361 which register is to be read. This is achieved by writing to the device a word whose first two bits are the special function code 00. The remaining bits then determine if the operation is a readback, and the register which is to be read back, or if it is a write to of the special function registers such as the control register.

After the special function write has been performed, if it is a readback command then data from the selected register will be clocked out of the SDO pin during the next SPI operation. The SDO pin is normally three-state but becomes driven as soon as a read command has been issued. The pin will remain driven until the registers data has been clocked out. See Figure 5 for the read timing diagram. Note that due to the timing requirements of  $t_s$  (25ns) the maximum speed of the SPI interface during a read operation should not exceed 20MHz.

### CHANNEL ADDRESSING AND SPECIAL MODES

If the mode bits are not 00, then the data word D15 to D0 is written to the device. Address bits A4 to A0 determine which channel or channels is/are written to, while the mode bits determine to which register (X1A, X1B, C or M) the data is written, as shown in Table 9 or Table 10. If data is to be written to the X1A or X1B register, the setting of the  $\bar{A}/B$  bit in the Control Register determines which register is used (0 → X1A, 1 → X1B).

**Table 11. Mode Bits**

M1	M0	Action
1	1	Write DAC input data (X1A or X1B) register, depending on Control Register $\bar{A}/B$ bit.
1	0	Write DAC offset (C) register
0	1	Write DAC gain (M) register
0	0	Special function, used in combination with other bits of word

The AD5360/AD5361 has very flexible addressing that allows writing of data to a single channel, all channels in a group, the same channel in groups 0 and 1, or all channels in the device. Table 12 shows all these address modes.

**Table 12. Group and Channel Addressing**

This table shows which group(s) and which channel(s) is/are addressed for every combination of address bits A4 to A0.

		ADDRESS BITS A4 TO A3			
		00	01	10	11
ADDRESS BITS A2 TO A0	000	All groups, all channels	Group 0, channel 0	Group 1, channel 0	Unused
	001	Group 0, all channels	Group 0, channel 1	Group 1, channel 1	Unused
	010	Group 1, all channels	Group 0, channel 2	Group 1, channel 2	Unused
	011	Unused	Group 0, channel 3	Group 1, channel 3	Unused
	100	Unused	Group 0, channel 4	Group 1, channel 4	Unused
	101	Unused	Group 0, channel 5	Group 1, channel 5	Unused
	110	Unused	Group 0, channel 6	Group 1, channel 6	Unused
	111	Unused	Group 0, channel 7	Group 1, channel 7	Unused

**SPECIAL FUNCTION MODE**

If the mode bits are 00, then the special function mode is selected, as shown in Table 13. Bits I21 to I16 of the serial data word select the special function, while the remaining bits are

data required for execution of the special function, for example the channel address for data readback.

The codes for the special functions are shown in Table 14. Table 15 shows the addresses for data readback.

**Table 13. Special Function Mode**

I23	I22	I21	I20	I19	I18	I17	I16	I15	I14	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
0	0	S5	S4	S3	S2	S1	S0	F15	F14	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2	F1	F0

**Table 14. Special Function Codes**

SPECIAL FUNCTION CODE						DATA	ACTION
S5	S4	S3	S2	S1	S0	F15-F0	
0	0	0	0	0	0	0000 0000 0000 0000	NOP
0	0	0	0	0	1	XXXX XXXX XXX[F4:F0]	Write control register F4 = 1 → Overtemperature; F4 = 0 → Temp OK (Read-only bit) F3 = 1 → PEC error; F3 = 0 → PEC OK (Read-only bit) F2 = 1 → Select B register for input; F2 = 0 → Select A register for input F1 = 1 → Enable temperature shutdown; F1 = 0 → Disable temperature shutdown F0 = 1 → Soft power down; F0 = 0 → Soft power up
0	0	0	0	1	0	[F13:F0]	Write data in F13:F0 to OFS0 register
0	0	0	0	1	1	[F13:F0]	Write data in F13:F0 to OFS1 register
0	0	0	1	0	1	See Table 15	Select register for readback
0	0	0	1	1	0	XXXX XXXX[F7:F0]	Write data in F7:F0 to A/B Select Register 0
0	0	0	1	1	1	XXXX XXXX[F7:F0]	Write data in F7:F0 to A/B Select Register 1
0	0	1	1	0	0	XXXX XXXX XX[F5:F0]	F5 = 1 → Monitor enable; F5 = 0 → Monitor disable F4 = 1 → Monitor input pin selected by IO (0 = MON_IN0, 1 = MON_IN1) F4 = 0 → Monitor DAC channel selected by F3:F0 (0000 = channel 0 → 1111 = channel 15)
0	0	1	1	0	1	XXXX XXXX XXXX XX[F1:F0]	GPIO configure and write F1 = 1 → GPIO is output. Data to output is written to F0 F1 = 0 → GPIO is input. Data can be read from F0 on readback

Note. When writing to the offset registers, the 14-bit data is right justified (bits F15 and F14 are don't care). When writing to the X, M or C registers of the AD5361, the 14-bit data is left-justified (bits 1 and 0 of the data word are don't care).

**Table 15. Address Codes for Data Readback**

F15	F14	F13	F12	F11	F10	F9	F8	F7	REGISTER READ <sup>1</sup>	
0	0	0	Bits F12 to F7 select channel to be read back, from Channel 0 = 001000 to Channel 15 = 010111						0	X1A Register
0	0	1							0	X1B Register
0	1	0							0	C Register
0	1	1							0	M Register
1	0	0	0	0	0	0	0	1	Control Register	
1	0	0	0	0	0	0	1	0	OFS0 Data Register	
1	0	0	0	0	0	0	1	1	OFS1 Data Register	
1	0	0	0	0	0	1	1	0	A/B Select Register 0	
1	0	0	0	0	0	1	1	1	A/B Select Register 1	
1	0	0	0	0	1	0	1	1	GPIO read (data in F0) <sup>2</sup>	

<sup>1</sup>F6 to F0 are don't care for data readback functions except for GPIO read.

<sup>2</sup>F6 to F0 should be 0 for GPIO read

**Table 16. DACs Select by A/B Select Registers**

A/B Select Register	Bits							
	F7	F6	F5	F4	F3	F2	F1	F0
0	VOUT7	VOUT6	VOUT5	VOUT4	VOUT3	VOUT2	VOUT1	VOUT0
1	VOUT15	VOUT14	VOUT13	VOUT12	VOUT11	VOUT10	VOUT9	VOUT8

## POWER SUPPLY DECOUPLING

In any circuit where accuracy is important, careful consideration of the power supply and ground return layout helps to ensure the rated performance. The printed circuit board on which the AD5360/AD5361 is mounted should be designed so that the analog and digital sections are separated and confined to certain areas of the board. If the AD5360/AD5361 is in a system where multiple devices require an AGND-to-DGND connection, the connection should be made at one point only. The star ground point should be established as close as possible to the device. For supplies with multiple pins ( $V_{SS}$ ,  $V_{DD}$ ,  $V_{CC}$ ), it is recommended to tie these pins together and to decouple each supply once.

The AD5360/AD5361 should have ample supply decoupling of 10  $\mu\text{F}$  in parallel with 0.1  $\mu\text{F}$  on each supply located as close to the package as possible, ideally right up against the device. The 10  $\mu\text{F}$  capacitors are the tantalum bead type. The 0.1  $\mu\text{F}$  capacitor should have low effective series resistance (ESR) and effective series inductance (ESI), such as the common ceramic types that provide a low impedance path to ground at high frequencies, to handle transient currents due to internal logic switching.

Digital lines running under the device should be avoided, because these couple noise onto the device. The analog ground plane should be allowed to run under the AD5362/AD5363 to avoid noise coupling. The power supply lines of the AD5362/AD5363 should use as large a trace as possible to provide low impedance paths and reduce the effects of glitches on the power supply line. Fast switching digital signals should be shielded with digital ground to avoid radiating noise to other parts of the board, and should never be run near the reference inputs. It is essential to minimize noise on all  $V_{REF}$  lines

Avoid crossover of digital and analog signals. Traces on opposite sides of the board should run at right angles to each other. This reduces the effects of feedthrough through the board. A microstrip technique is by far the best, but not always possible with a double-sided board. In this technique, the component side of the board is dedicated to ground plane, while signal traces are placed on the solder side.

As is the case for all thin packages, care must be taken to avoid flexing the package and to avoid a point load on the surface of this package during the assembly process.

## POWER SUPPLY SEQUENCING

When the supplies are connected to the AD5360/AD5361 it is important that the AGND and DGND pins are connected to the relevant ground plane before the positive or negative supplies are applied. In most applications this is not an issue as the ground pins for the power supplies will be connected to the ground pins of the AD5360/AD5361 via ground planes. Where the AD5360/AD5361 is to be used in a hot-swap card care should be taken to ensure that the ground pins are connected to the supply grounds before the positive or negative supplies are connected. This is required to prevent currents flowing in directions other than towards an analog or digital ground.

**INTERFACING EXAMPLES**

The SPI interface of the AD5360 and AD5361 are designed to allow the parts to be easily connected to industry standard DSPs and micro-controllers. Figure 12 shows how the AD5360/AD5361 could be connected to the Analog Devices Blackfin® DSP. The Blackfin has an integrated SPI port which can be connected directly to the SPI pins of the AD5360 or AD5361 and programmable I/O pins which can be used to set or read the state of the digital input or output pins associated with the interface.

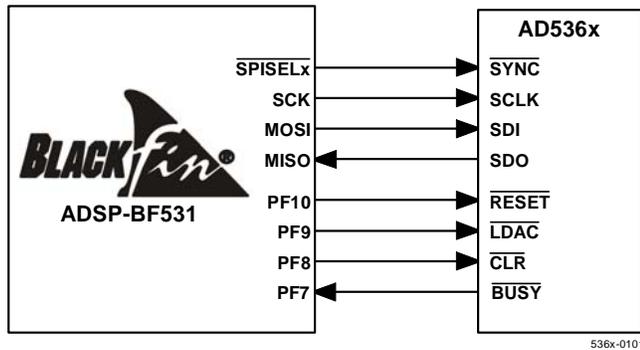


Figure 12. Interfacing to a Blackfin DSP

The Analog Devices ADSP-21065L is a floating point DSP with two serial ports (SPORTS). Figure 13 shows how one SPORT can be used to control the AD5360 or AD5361. In this example the Transmit Frame Synchronization (TFS) pin is connected to

the Receive Frame Synchronization (RFS) pin. Similarly the transmit and receive clocks (TCLK and RCLK) are also connected together. The user can write to the AD5360 or AD5361 by writing to the transmit register. A read operation can be accomplished by first writing to the AD5360/AD5361 to tell the part that a read operation is required. A second write operation with a NOP instruction will cause the data to be read from the AD5360/AD5361. The DSP's receive interrupt can be used to indicate when the read operation is complete.

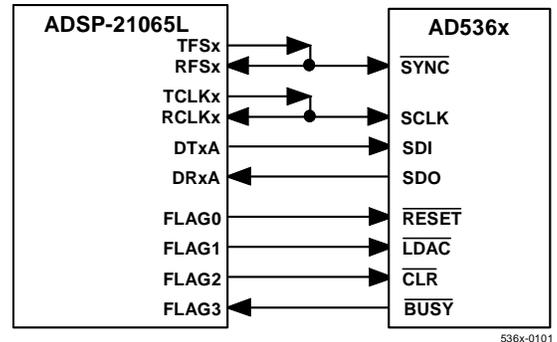
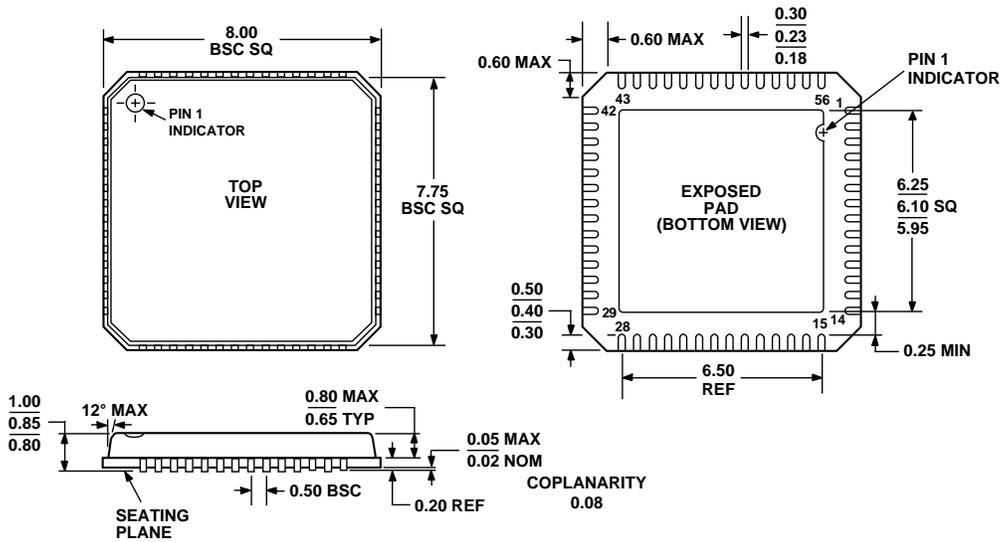


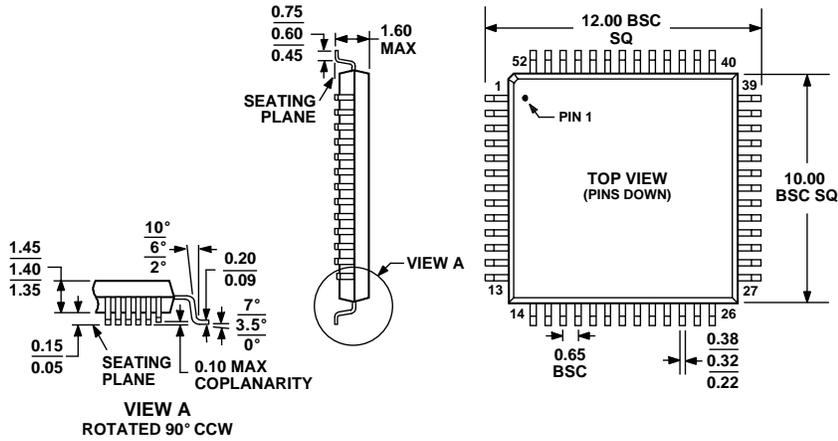
Figure 13. Interfacing to an ADSP-21065L DSP

OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-220-VLLD-2

Figure 14. 56 Lead LFCSP Package  
Dimensions shown in millimeters



COMPLIANT TO JEDEC STANDARDS MS-026BCC

Figure 15. 52 Lead LQFP Package  
Dimensions shown in millimeters

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD5360BCPZ	-40°C to +85°C	56-Lead Free Chip Scale Package (LFCSP)	CP-56
AD5360BSTZ	-40°C to +85°C	52-Lead Quad Flat Pack (LQFP)	ST-52
AD5361BCPZ	-40°C to +85°C	56-Lead Free Chip Scale Package (LFCSP)	CP-56
AD5361BSTZ	-40°C to +85°C	52-Lead Quad Flat Pack (LQFP)	ST-52

## NOTES