

### FEATURES

- Current sink: 120 mA
- 2-wire, (I<sup>2</sup>C-compatible) 1.8 V serial interface
- 10-bit resolution
- Integrated current sense resistor
- Power supply: 2.7 V to 5.5 V
- Guaranteed monotonic over all codes
- Power down to: 0.5  $\mu$ A typical
- Internal reference
- Ultralow noise preamplifier
- Power-down function
- Power-on reset
- Available in 3  $\times$  3 array WLCSP package

### APPLICATIONS

#### Consumer

- Lens autofocus
- Image stabilization
- Optical zoom
- Shutters
- Iris/exposure
- Neutral density (ND) filters
- Lens covers
- Camera phones
- Digital still cameras
- Camera modules
- Digital video cameras/camcorders
- Camera-enabled devices
- Security cameras
- Web/PC cameras

#### Industrial

- Heater control
- Fan control
- Cooler (Peltier) control
- Solenoid control
- Valve control
- Linear actuator control
- Light control
- Current loop control

### GENERAL DESCRIPTION

The AD5398A is a single, 10-bit digital-to-analog converter (DAC) with a current sink output capability of 120 mA. This device features an internal reference and operates from a single 2.7 V to 5.5 V supply. The DAC is controlled via a 2-wire (1.8 V, I<sup>2</sup>C\*-compatible) serial interface that operates at clock rates up to 400 kHz.

The AD5398A incorporates a power-on reset circuit, which ensures the DAC output powers up to 0 V and remains there until a valid write takes place. It has a power-down feature that reduces the current consumption of the device to 0.5  $\mu$ A typically.

The AD5398A is designed for autofocus, image stabilization, and optical zoom applications in camera phones, digital still cameras, and camcorders. The AD5398A is also suitable for many industrial applications, such as controlling temperature, light, and movement without derating, over temperatures ranging from  $-30^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ . The I<sup>2</sup>C address range for the AD5398A is 0x18 to 0x1F inclusive.

### FUNCTIONAL BLOCK DIAGRAM

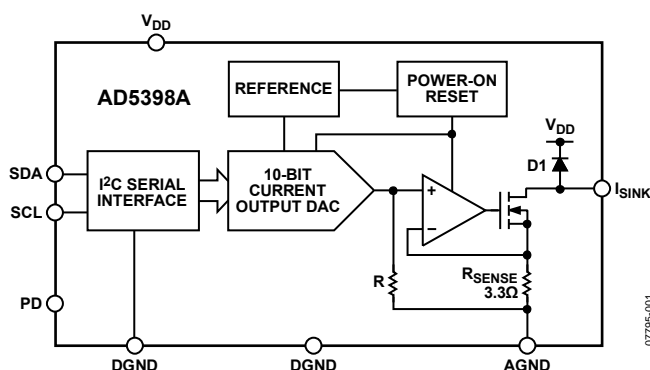


Figure 1.

#### Rev. 0

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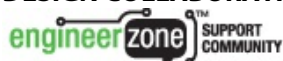
## DOCUMENTATION

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REVISION HISTORY

10/08—Revision 0: Initial Version

## SPECIFICATIONS

$V_{DD} = 2.7\text{ V to }5.5\text{ V}$ ,  $AGND = DGND = 0\text{ V}$ , load resistance ( $R_L$ ) =  $25\ \Omega$  connected to  $V_{DD}$ ; all specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

Table 1.

Parameter	Min	B Version <sup>1</sup> Typ	Max	Unit	Test Conditions/Comments
DC PERFORMANCE					$V_{DD} = 3.6\text{ V to }4.5\text{ V}$ ; device operates over $2.7\text{ V to }5.5\text{ V}$ with reduced performance
Resolution		10		Bits	117 $\mu\text{A/LSB}$
Relative Accuracy <sup>2</sup>		$\pm 1.5$	$\pm 4$	LSB	
Differential Nonlinearity <sup>2, 3</sup>			$\pm 1$	LSB	Guaranteed monotonic over all codes
Zero Code Error <sup>2, 4</sup>	0	0.5	1	mA	All 0s loaded to DAC
Offset Error @ Code 16 <sup>2</sup>		0.5		mA	
Gain Error <sup>2</sup>			$\pm 0.6$	% of FSR	at $25^\circ\text{C}$
Offset Error Drift <sup>2, 4, 5</sup>		10		$\mu\text{A}/^\circ\text{C}$	
Gain Error Drift <sup>2, 5</sup>		$\pm 0.2$	$\pm 0.5$	LSB/ $^\circ\text{C}$	
OUTPUT CHARACTERISTICS					
Minimum Sink Current <sup>4</sup>		3		mA	
Maximum Sink Current		120		mA	$V_{DD} = 3.6\text{ V to }4.5\text{ V}$ ; device operates over $2.7\text{ V to }5.5\text{ V}$ ; specified maximum sink current may not be achieved
Output Current During PD <sup>5</sup>		80		nA	PD = 1
Output Compliance <sup>5</sup>	0.6		$V_{DD}$	V	Output voltage range over which maximum 120 mA sink current is available
Output Compliance <sup>5</sup>	0.48		$V_{DD}$	V	Output voltage range over which 90 mA sink current is available
Power-Up Time <sup>5</sup>		20		$\mu\text{s}$	To 10% of FS, coming out of power-down mode; $V_{DD} = 5\text{ V}$
LOGIC INPUT (PD) <sup>5</sup>					
Input Current			$\pm 1$	$\mu\text{A}$	
Input Low Voltage, $V_{INL}$			0.54	V	$V_{DD} = 2.7\text{ V to }5.5\text{ V}$
Input High Voltage, $V_{INH}$	1.26			V	$V_{DD} = 2.7\text{ V to }5.5\text{ V}$
Pin Capacitance		3		pF	
LOGIC INPUTS (SCL, SDA) <sup>5</sup>					
Input Low Voltage, $V_{INL}$	-0.3		+0.54	V	$V_{DD} = 2.7\text{ V to }3.6\text{ V}$
Input High Voltage, $V_{INH}$	1.26		$V_{DD} + 0.3$	V	$V_{DD} = 2.7\text{ V to }3.6\text{ V}$
Input Low Voltage, $V_{INL}$	-0.3		+0.54	V	$V_{DD} = 3.6\text{ V to }5.5\text{ V}$
Input High Voltage, $V_{INH}$	1.4		$V_{DD} + 0.3$	V	$V_{DD} = 3.6\text{ V to }5.5\text{ V}$
Input Leakage Current, $I_{IN}$			$\pm 1$	$\mu\text{A}$	$V_{IN} = 0\text{ V to }V_{DD}$
Input Hysteresis, $V_{HYST}$	0.05 $V_{DD}$			V	
Digital Input Capacitance, $C_{IN}$		6		pF	
Glitch Rejection <sup>6</sup>			50	ns	Pulse width of spike suppressed
POWER REQUIREMENTS					
$V_{DD}$	2.7		5.5	V	
$I_{DD}$ (Normal Mode)		0.5	1	mA	$I_{DD}$ specification is valid for all DAC codes; $V_{IH} = V_{DD}$ , $V_{IL} = \text{GND}$ , $V_{DD} = 5.5\text{ V}$
$I_{DD}$ (Power-Down Mode) <sup>7</sup>		0.5		$\mu\text{A}$	$V_{IH} = V_{DD}$ , $V_{IL} = \text{GND}$ , $V_{DD} = 3\text{ V}$

<sup>1</sup> Temperature range for the B version is  $-30^\circ\text{C}$  to  $+85^\circ\text{C}$ .

<sup>2</sup> See the Terminology section.

<sup>3</sup> Linearity is tested using a reduced code range: Code 32 to Code 1023.

<sup>4</sup> To achieve near zero output current, use the power-down feature.

<sup>5</sup> Guaranteed by design and characterization; not production tested. PD is active high. SDA and SCL pull-up resistors are tied to 1.8 V.

<sup>6</sup> Input filtering on both the SCL and SDA inputs suppresses noise spikes that are less than 50 ns.

<sup>7</sup> PD is active high. When PD is taken high, the AD5389A enters power-down mode.

# AD5398A

## AC SPECIFICATIONS

$V_{DD} = 2.7\text{ V}$  to  $5.5\text{ V}$ ,  $AGND = DGND = 0\text{ V}$ ,  $R_L = 25\ \Omega$  connected to  $V_{DD}$ , unless otherwise noted.

Table 2.

Parameter	B Version <sup>1,2</sup>			Unit	Test Conditions/Comments
	Min	Typ	Max		
Output Current Settling Time		250		$\mu\text{s}$	$V_{DD} = 5\text{ V}$ , $R_L = 25\ \Omega$ , $L_L = 680\ \mu\text{H}$ ¼ scale to ¾ scale change (0x100 to 0x300)
Slew Rate		0.3		$\text{mA}/\mu\text{s}$	
Major Code Change Glitch Impulse		0.15		$\text{nA}\cdot\text{sec}$	1 LSB change around major carry
Digital Feedthrough <sup>3</sup>		0.06		$\text{nA}\cdot\text{sec}$	

<sup>1</sup> Temperature range for the B version is  $-30^\circ\text{C}$  to  $+85^\circ\text{C}$ .

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

<sup>3</sup> See the Terminology section.

## TIMING SPECIFICATIONS

$V_{DD} = 2.7\text{ V}$  to  $5.5\text{ V}$ . All specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

Table 3.

Parameter <sup>1</sup>	B Version Limit at $T_{MIN}$ , $T_{MAX}$	Unit	Description
$f_{SCL}$	400	$\text{kHz max}$	SCL clock frequency
$t_1$	2.5	$\mu\text{s min}$	SCL cycle time
$t_2$	0.6	$\mu\text{s min}$	$t_{HIGH}$ , SCL high time
$t_3$	1.3	$\mu\text{s min}$	$t_{LOW}$ , SCL low time
$t_4$	0.6	$\mu\text{s min}$	$t_{HD, STA}$ , start/repeated start condition hold time
$t_5$	100	$\text{ns min}$	$t_{SU, DAT}$ , data setup time
$t_6^2$	0.9	$\mu\text{s max}$	$t_{HD, DAT}$ , data hold time
	0	$\mu\text{s min}$	
$t_7$	0.6	$\mu\text{s min}$	$t_{SU, STA}$ , setup time for repeated start
$t_8$	0.6	$\mu\text{s min}$	$t_{SU, STO}$ , stop condition setup time
$t_9$	1.3	$\mu\text{s min}$	$t_{BUF}$ , bus free time between a stop condition and a start condition
$t_{10}$	300	$\text{ns max}$	$t_R$ , rise time of both SCL and SDA when receiving
	0	$\text{ns min}$	Can be CMOS driven
$t_{11}$	250	$\text{ns max}$	$t_F$ , fall time of SDA when receiving
	300	$\text{ns max}$	$t_F$ , fall time of both SCL and SDA when transmitting
	$20 + 0.1 C_b^3$	$\text{ns min}$	
$C_b$	400	$\text{pF max}$	Capacitive load for each bus line

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

<sup>2</sup> A master device must provide a hold time of at least 300 ns for the SDA signal (referred to the  $V_{IH, MIN}$  of the SCL signal) to bridge the undefined region of the SCL falling edge.

<sup>3</sup>  $C_b$  is the total capacitance of one bus line in pF.  $t_R$  and  $t_F$  are measured between  $0.3 V_{DD}$  and  $0.7 V_{DD}$ .

### Timing Diagram

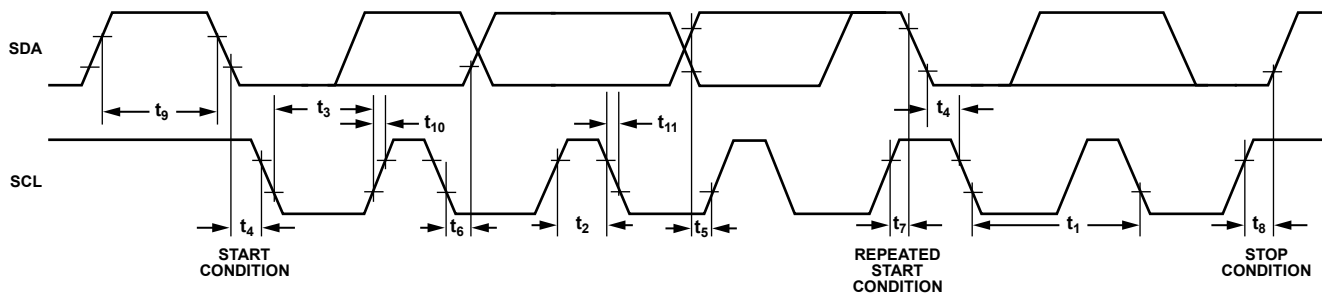


Figure 2. 2-Wire Serial Interface Timing Diagram

07795-002

## ABSOLUTE MAXIMUM RATINGS

$T_A = 25^\circ\text{C}$ , unless otherwise noted.<sup>1</sup>

**Table 4.**

Parameter	Rating
$V_{DD}$ to AGND	−0.3 V to +7 V
$V_{DD}$ to DGND	−0.3 V to $V_{DD} + 0.3$ V
AGND to DGND	−0.3 V to +0.3 V
SCL, SDA to DGND	−0.3 V to $V_{DD} + 0.3$ V
PD to DGND	−0.3 V to $V_{DD} + 0.3$ V
$I_{SINK}$ to AGND	−0.3 V to $V_{DD} + 0.3$ V
Operating Temperature Range	
Industrial (B Version)	−40°C to +85°C
Storage Temperature Range	−65°C to +150°C
Junction Temperature ( $T_J$ max)	150°C
$\theta_{JA}$ Thermal Impedance <sup>2</sup>	
Mounted on 2-Layer Board	84°C/W
Mounted on 4-Layer Board	48°C/W
Lead Temperature, Soldering	
Maximum Peak Reflow Temperature <sup>3</sup>	260°C ( $\pm 5^\circ\text{C}$ )

<sup>1</sup>Transient currents of up to 100 mA do not cause SCR latch-up.

<sup>2</sup>To achieve the optimum  $\theta_{JA}$ , it is recommended that the AD5398A be soldered onto a 4-layer board.

<sup>3</sup>As per JEDEC J-STD-020C.

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. Only one absolute maximum rating may be applied at any one time.

### ESD CAUTION



#### **ESD (electrostatic discharge) sensitive device.**

Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

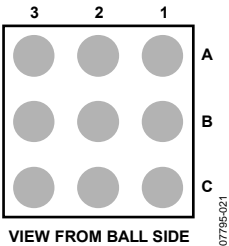


Figure 3. 9-Ball WLCSP Pin Configuration

Table 5. 9-Ball WLCSP Pin Function Description

Pin Number	Mnemonic	Description
A1	ISINK	Output Current Sink.
A2	NC	No Connection.
A3	PD	Power-Down. Asynchronous power-down signal.
B1	AGND	Analog Ground Pin.
B2	DGND	Digital Ground Pin.
B3	SDA	I <sup>2</sup> C Interface Signal.
C1	DGND	Digital Ground Pin.
C2	V <sub>DD</sub>	Digital Supply Voltage.
C3	SCL	I <sup>2</sup> C Interface Signal.

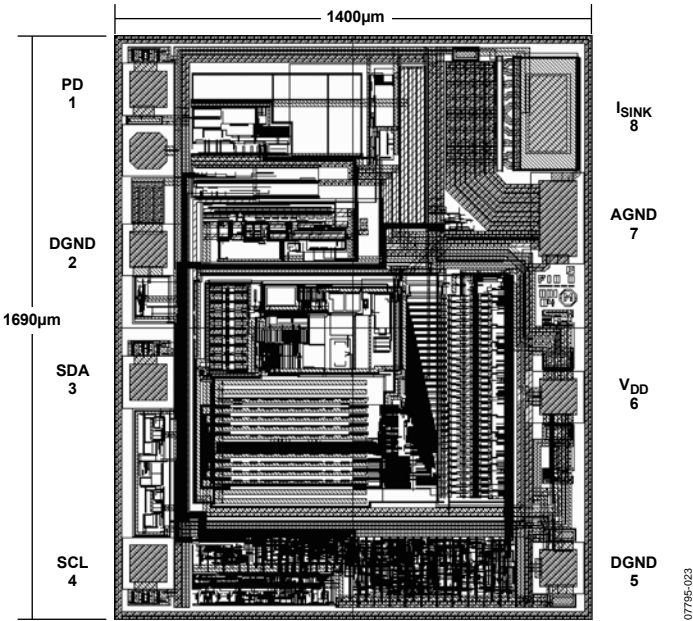


Figure 4. Metallization Photograph  
Dimensions shown in µm  
Contact Factory for Latest Dimensions

## TYPICAL PERFORMANCE CHARACTERISTICS

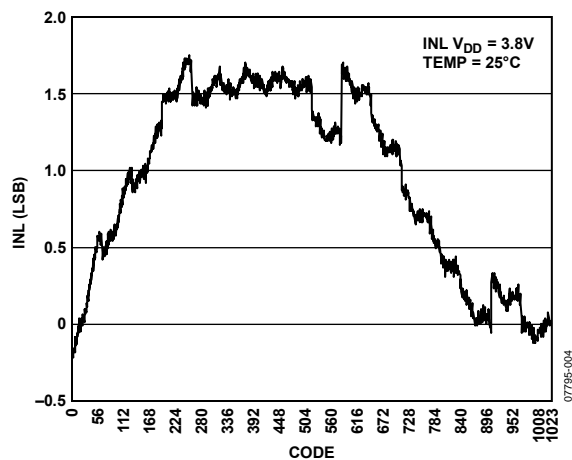


Figure 5. Typical INL vs. Code Plot

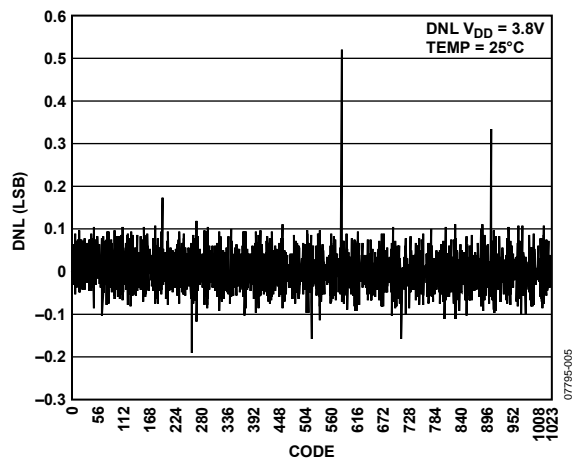
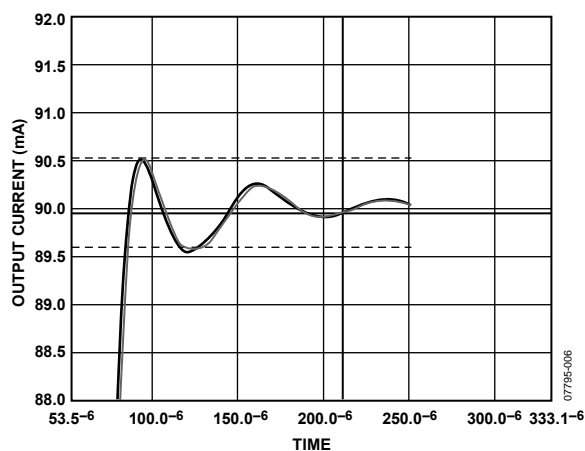
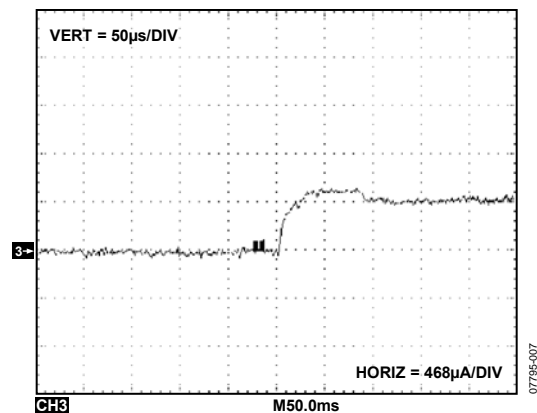
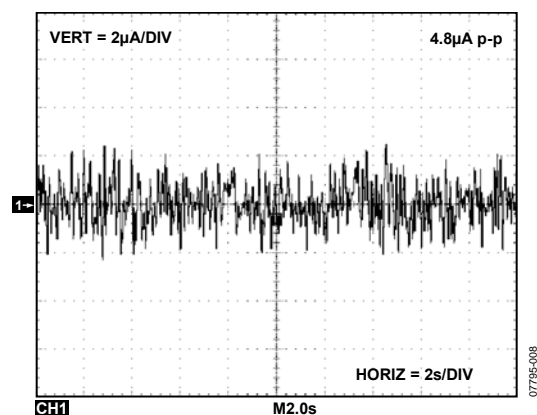
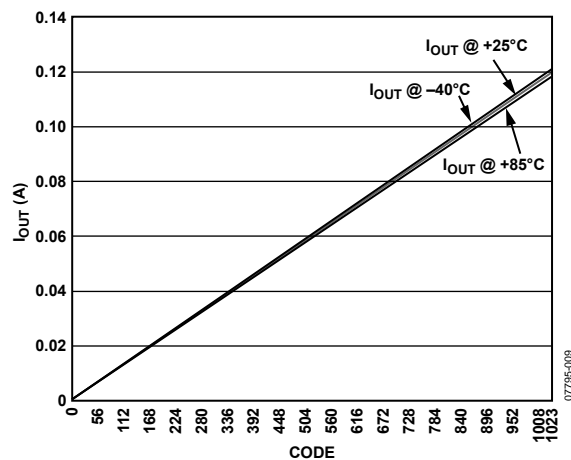


Figure 6. Typical DNL vs. Code Plot

Figure 7. 1/4 to 3/4 Scale Settling Time ( $V_{DD} = 3.6\text{ V}$ )Figure 8. Settling Time for a 4-LSB Step ( $V_{DD} = 3.6\text{ V}$ )Figure 9. 0.1 Hz to 10 Hz Noise Plot ( $V_{DD} = 3.6\text{ V}$ )Figure 10. Sink Current vs. Code vs. Temperature ( $V_{DD} = 3.6\text{ V}$ )



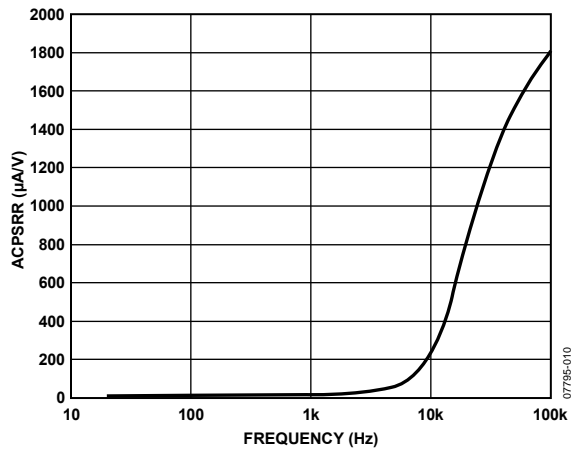


Figure 11. AC Power Supply Rejection Ratio ( $V_{DD} = 3.6 V$ )

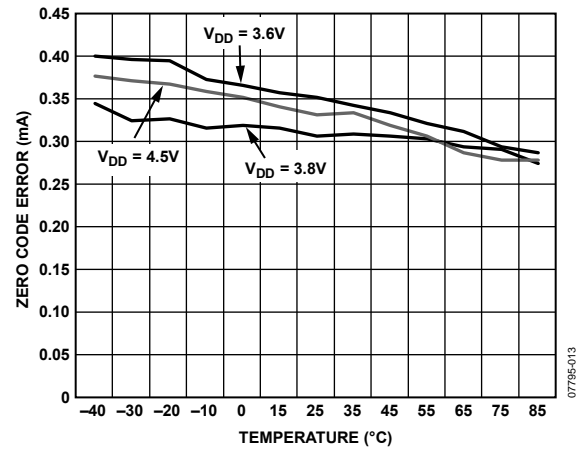


Figure 14. Zero Code Error vs. Temperature vs. Supply Voltage

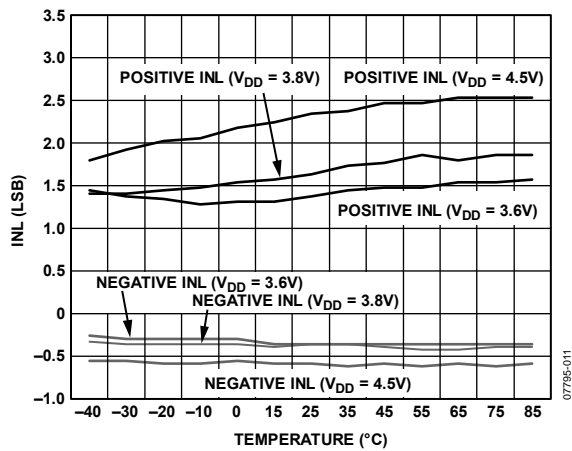


Figure 12. INL vs. Temperature vs. Supply Voltage

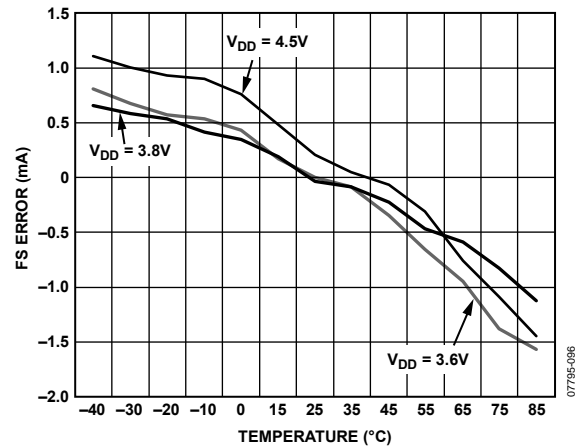


Figure 15. Full-Scale Error vs. Temperature vs. Supply Voltage

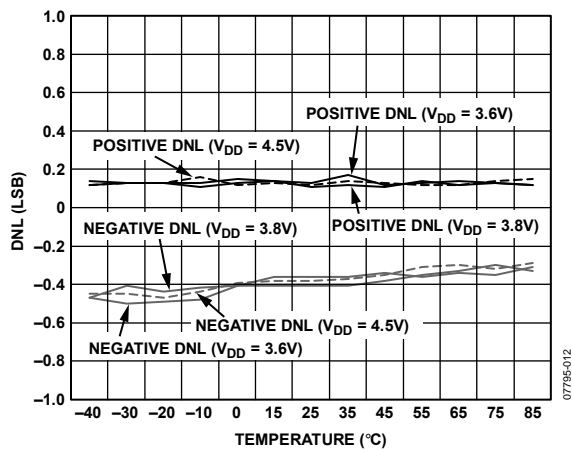


Figure 13. DNL vs. Temperature vs. Supply Voltage

## TERMINOLOGY

### Relative Accuracy

For the DAC, relative accuracy or integral nonlinearity is a measurement of the maximum deviation, in LSB, from a straight line passing through the endpoints of the DAC transfer function. A typical INL vs. code plot is shown in Figure 5.

### 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  $\pm 1$  LSB maximum ensures monotonicity. This DAC is guaranteed monotonic by design. A typical DNL vs. code plot is shown in Figure 6.

### 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 is 0 mA. The zero-code error is always positive in the AD5398A because the output of the DAC cannot go below 0 mA. This is due to a combination of the offset errors in the DAC and output amplifier. Zero-code error is expressed in mA.

### Gain Error

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

### Gain Error Drift

This is a measurement of the change in gain error with changes in temperature. It is expressed in LSB/°C.

### 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 nA-sec and is measured when the digital input code is changed by 1 LSB at the major carry transition.

### Digital Feedthrough

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

### Offset Error

Offset error is a measurement of the difference between  $I_{\text{SINK}}$  (actual) and  $I_{\text{OUT}}$  (ideal) in the linear region of the transfer function, expressed in mA. Offset error is measured on the AD5398A with Code 16 loaded into the DAC register.

### Offset Error Drift

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



## DATA FORMAT

Data is written to the AD5398A high byte first, MSB first, and is shifted into the 16-bit input register. After all data is shifted in, data from the input register is transferred to the DAC register.

Because the DAC requires only 10 bits of data, not all bits of the input register data are used. The MSB is reserved for an active-high, software-controlled, power-down function.

The data format is shown in Table 6. When referring to this table, note that Bit 14 is unused; Bit 13 to Bit 4 correspond to the DAC data bits, D9 to D0; and Bit 3 to Bit 0 are unused.

During a read operation, data is read in the same bit order.

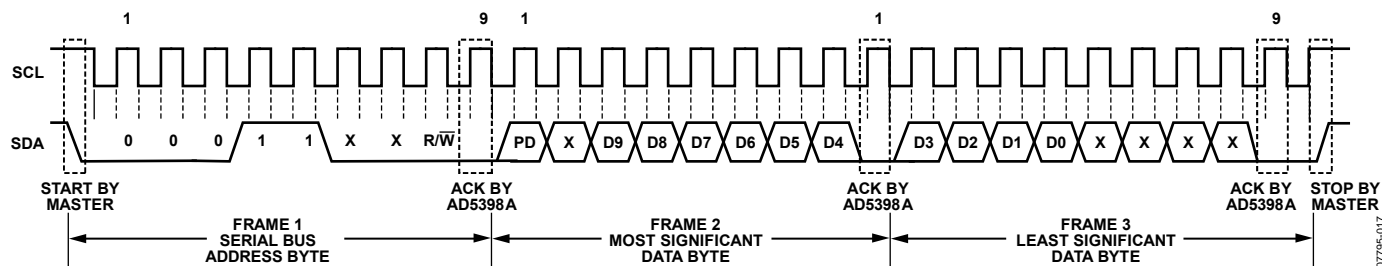


Figure 18. Write Operation

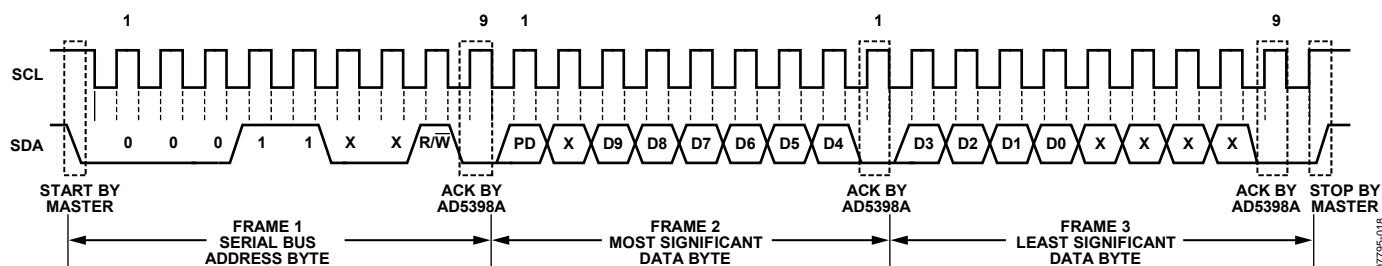


Figure 19. Read Operation

Table 6. Data Format

Serial Data- Words	High Byte								Low Byte							
	Bit 15	Bit 14	Bit 13	Bit 12	Bit 11	Bit 10	Bit 9	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Serial Data Bits	SD7	SD6	SD5	SD4	SD3	SD2	SD1	SD0	SD7	SD6	SD5	SD4	SD3	SD2	SD1	SD0
Input Register	R15	R14	R13	R12	R11	R10	R9	R8	R7	R6	R5	R4	R3	R2	R1	R0
Function <sup>1</sup>	PD	X	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0	X	X	X	X

<sup>1</sup> PD = soft power-down; X = unused/don't care; and D7 to D0 = DAC data.

## POWER SUPPLY BYPASSING AND GROUNDING

When accuracy is important in an application, it is beneficial to consider power supply and ground return layout on the PCB. The PCB for the AD5398A should have separate analog and digital power supply sections. Where shared AGND and DGND is necessary, the connection of grounds should be made at only one point, as close as possible to the AD5398A.

Pay special attention to the layout of the AGND return path and track it between the voice coil motor and  $I_{SINK}$  to minimize any series resistance. Figure 20 shows the output current sink of the AD5398A and illustrates the importance of reducing the effective series impedance of AGND, and the track resistance between the motor and  $I_{SINK}$ . The voice coil is modelled as Inductor  $L_C$  and Resistor  $R_C$ . The current through the voice coil is effectively a dc current that results in a voltage drop,  $V_C$ , when the AD5398A is sinking current; the effect of any series inductance is minimal. The maximum voltage drop allowed across  $R_{SENSE}$  is 400 mV, and the minimum drain to source voltage of Q1 is 200 mV. This means that the AD5398A output has a compliance voltage of 600 mV. If  $V_{DROP}$  falls below 600 mV, the output transistor, Q1, can no longer operate properly and  $I_{SINK}$  might not be maintained as a constant.

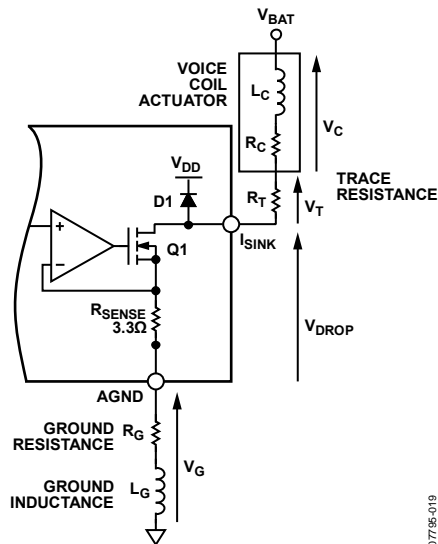


Figure 20. Effect of PCB Trace Resistance and Inductance

As the current increases through the voice coil,  $V_C$  increases and  $V_{DROP}$  decreases and eventually approaches the minimum specified compliance voltage of 600 mV. The ground return path is modelled by the  $R_G$  and  $L_G$  components. The track resistance between the voice coil and the AD5398A is modelled as  $R_T$ . The inductive effects of  $L_G$  influence  $R_{SENSE}$  and  $R_C$  equally, and because the current is maintained as a constant, it is not as critical as the purely resistive component of the ground return path.

When the maximum sink current is flowing through the motor, the resistive elements,  $R_T$  and  $R_G$ , may have an impact on the voltage headroom of Q1 and may, in turn, limit the maximum value of  $R_C$  because of voltage compliance.

For example, if

$$V_{BAT} = 3.6 \text{ V}$$

$$R_G = 0.5 \Omega$$

$$R_T = 0.5 \Omega$$

$$I_{SINK} = 120 \text{ mA}$$

$$V_{DROP} = 600 \text{ mV (the compliance voltage)}$$

then the largest value of resistance of the voice coil,  $R_C$ , is

$$R_C = \frac{V_{BAT} - [V_{DROP} + (I_{SINK} \times R_T) + (I_{SINK} \times R_G)]}{I_{SINK}} = \frac{3.6 \text{ V} - [600 \text{ mV} + 2 \times (120 \text{ mA} \times 0.5 \Omega)]}{120 \text{ mA}} = 24 \Omega$$

For this reason, it is important to minimize any series impedance on both the ground return path and interconnect between the AD5398A and the motor.

The power supply of the AD5398A should be decoupled with 0.1  $\mu\text{F}$  and 10  $\mu\text{F}$  capacitors. These capacitors should be kept as physically close as possible, with the 0.1  $\mu\text{F}$  capacitor serving as a local bypass capacitor, and therefore should be located as close as possible to the  $V_{DD}$  pin. The 10  $\mu\text{F}$  capacitor should be a tantalum bead-type; the 0.1  $\mu\text{F}$  capacitor should be a ceramic type with a low effective series resistance and effective series inductance. The 0.1  $\mu\text{F}$  capacitor provides a low impedance path to ground for high transient currents.

The power supply line should have as large a trace as possible to provide a low impedance path and 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 to use a multilayer board with ground and power planes, 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.

## APPLICATIONS INFORMATION

The AD5398A is designed to drive both spring preloaded and nonspring linear motors used in applications such as lens autofocus, image stabilization, or optical zoom. The operating principle of the spring-preloaded motor is that the lens position is controlled by the balancing of a voice coil and a spring. Figure 21 shows the transfer curve of a typical spring preloaded linear motor for autofocus. The key points of this transfer function are displacement or stroke, which is the actual distance the lens moves in millimeters (mm), and the current through the motor in milliamperes (mA).

A start current is associated with spring-preloaded linear motors, which is effectively a threshold current that must be exceeded for any displacement in the lens to occur. The start current is usually 20 mA or greater; the rated stroke or displacement is usually 0.25 mm to 0.4 mm; and the slope of the transfer curve is approximately 10  $\mu\text{m}/\text{mA}$  or less.

The AD5398A is designed to sink up to 120 mA, which is more than adequate for available commercial linear motors or voice coils. Another factor that makes the AD5398A the ideal solution for these applications is the monotonicity of the device, which ensures that lens positioning is repeatable for the application of a given digital word.

Figure 22 shows a typical application circuit for the AD5398A.

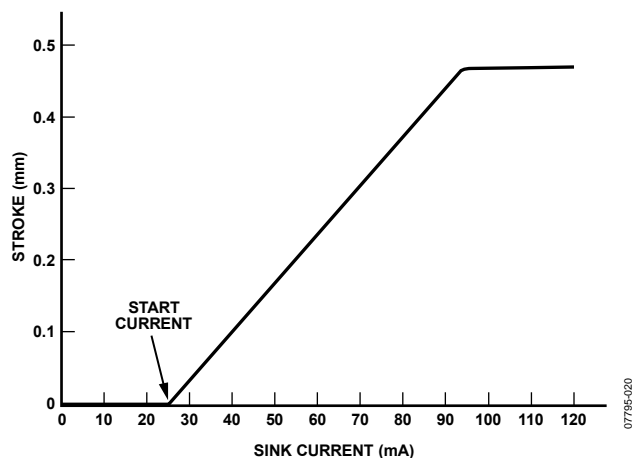


Figure 21. Spring Preloaded Voice Coil Stroke vs. Sink Current

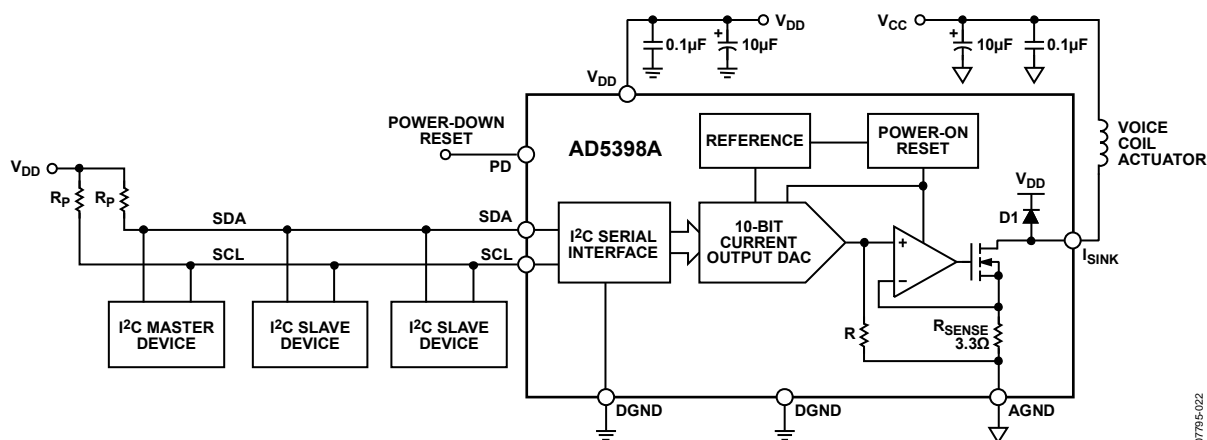


Figure 22. Typical Application Circuit



## NOTES



**AD5398A**

## NOTES

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