



# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

MAX5302

## General Description

The MAX5302 combines a low-power, voltage-output, 12-bit digital-to-analog converter (DAC) and a precision output amplifier in an 8-pin  $\mu$ MAX package. It operates from a single +5V supply, drawing less than 280 $\mu$ A of supply current.

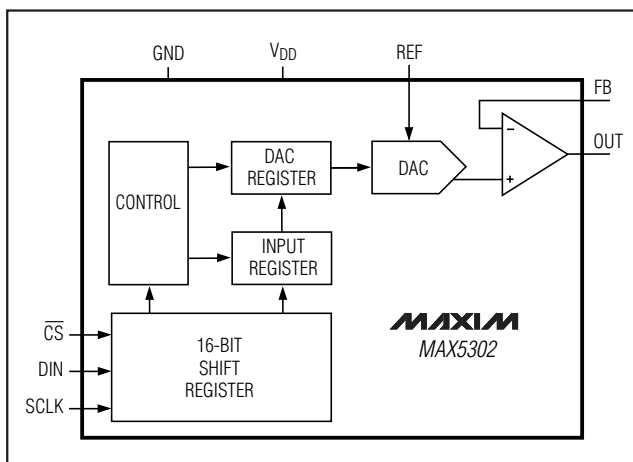
The output amplifier's inverting input is available to the user, allowing specific gain configurations, remote sensing, and high output current capability. This makes the MAX5302 ideal for a wide range of applications, including industrial process control. Other features include a software shutdown and power-on reset.

The serial interface is SPI™/QSPI™/MICROWIRE™ compatible. The DAC has a double-buffered input, organized as an input register followed by a DAC register. A 16-bit serial word loads data into the input register. The DAC register can be updated independently or simultaneously with the input register. All logic inputs are TTL/CMOS-logic compatible and buffered with Schmitt triggers to allow direct interfacing to optocouplers.

## Applications

- Industrial Process Control
- Automatic Test Equipment
- Digital Offset and Gain Adjustment
- Motion Control
- Remote Industrial Control
- Microprocessor-Controlled Systems

## Functional Diagram



SPI and QSPI are trademarks of Motorola, Inc.  
MICROWIRE is a trademark of National Semiconductor Corp.

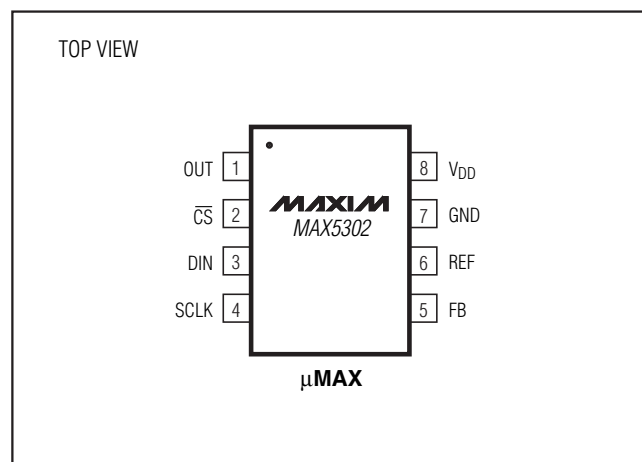
## Features

- ◆ 12-Bit DAC with Configurable Output Amplifier
- ◆ +5V Single-Supply Operation
- ◆ Low Supply Current: 0.28mA Normal Operation  
2 $\mu$ A Shutdown Mode
- ◆ Available in 8-Pin  $\mu$ MAX
- ◆ Power-On Reset Clears DAC Output to Zero
- ◆ SPI/QSPI/MICROWIRE Compatible
- ◆ Schmitt-Trigger Digital Inputs for Direct Optocoupler Interface

## Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX5302CUA	0°C to +70°C	8 $\mu$ MAX
MAX5302EUA	-40°C to +85°C	8 $\mu$ MAX

## Pin Configuration



Maxim Integrated Products 1

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# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

## ABSOLUTE MAXIMUM RATINGS

V <sub>DD</sub> to GND	-0.3V to +6V
REF, OUT, FB to GND	-0.3V to (V <sub>DD</sub> + 0.3V)
Digital Inputs to GND	-0.3V to +6V
Continuous Current into Any Pin	±20mA
Continuous Power Dissipation (T <sub>A</sub> = +70°C)	
8-Pin μMAX (derate 4.10mW/°C above +70°C)	330mW

Operating Temperature Ranges	
MAX5302CUA	0°C to +70°C
MAX5302EUA	-40°C to +85°C
Junction Temperature	+150°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (soldering, 10sec)	+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS

(Circuit of Figure 8, V<sub>DD</sub> = +5V ±10%, V<sub>REF</sub> = +2.5V, R<sub>L</sub> = 5kΩ, C<sub>L</sub> = 100pF, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C. Output buffer connected in unity-gain configuration.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>STATIC PERFORMANCE—ANALOG SECTION</b>						
Resolution	N		12			Bits
Differential Nonlinearity	DNL	Guaranteed monotonic			±1.0	LSB
Integral Nonlinearity (Note 1)	INL				±4	LSB
Offset Error	V <sub>OS</sub>			±0.3	±8	mV
Offset-Error Tempco	TCV <sub>OS</sub>			6		ppm/°C
Gain Error (Note 1)	GE			-0.3	±3	LSB
Gain-Error Tempco				1		ppm/°C
Power-Supply Rejection Ratio	PSRR	4.5V ≤ V <sub>DD</sub> ≤ 5.5V			800	μV/V
<b>REFERENCE INPUT</b>						
Reference Input Range	V <sub>REF</sub>		0		V <sub>DD</sub> - 1.4	V
Reference Input Resistance	R <sub>REF</sub>	Code dependent, minimum at code 1554 hex	14	20		kΩ
<b>MULTIPLYING-MODE PERFORMANCE</b>						
Reference -3dB Bandwidth		V <sub>REF</sub> = 0.67Vp-p		650		kHz
Reference Feedthrough		Input code = all 0s, V <sub>REF</sub> = 3.6Vp-p at 1kHz		-84		dB
Signal-to-Noise Plus Distortion Ratio	SINAD	V <sub>REF</sub> = 1Vp-p at 25kHz, code = full scale		77		dB
<b>DIGITAL INPUTS</b>						
Input Voltage High	V <sub>IH</sub>		2.4			V
Input Voltage Low	V <sub>IL</sub>				0.8	V
Input Leakage Current	I <sub>IN</sub>	V <sub>IN</sub> = 0 or V <sub>DD</sub>		0.001	±0.5	μA
Input Capacitance	C <sub>IN</sub>			8		pF

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

MAX5302

## ELECTRICAL CHARACTERISTICS (continued)

(Circuit of Figure 8,  $V_{DD} = +5V \pm 10\%$ ,  $V_{REF} = +2.5V$ ,  $R_L = 5k\Omega$ ,  $C_L = 100pF$ ,  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ . Output buffer connected in unity-gain configuration.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>DYNAMIC PERFORMANCE</b>						
Voltage Output Slew Rate	SR			0.6		V/ $\mu$ s
Output Settling Time		$T_o \pm 1/2LSB$ , $V_{STEP} = 2.5V$		14		$\mu$ s
Output Voltage Swing		Rail-to-rail (Note 2)		0 to $V_{DD}$		V
Current into FB				0.001	$\pm 0.1$	$\mu$ A
Start-Up Time				20		$\mu$ s
Digital Feedthrough		$\overline{CS} = V_{DD}$ , $DIN = 100kHz$		5		nVs
<b>POWER SUPPLIES</b>						
Supply Voltage	$V_{DD}$		4.5		5.5	V
Supply Current	$I_{DD}$	(Note 3)		0.28	0.4	mA
Supply Current in Shutdown		(Note 3)		4	20	$\mu$ A
Reference Current in Shutdown				0.001	$\pm 0.5$	$\mu$ A
<b>TIMING CHARACTERISTICS</b> (Figure 6)						
SCLK Clock Period	tCP		100			ns
SCLK Pulse Width High	tCH		40			ns
SCLK Pulse Width Low	tCL		40			ns
$\overline{CS}$ Fall to SCLK Rise Setup Time	tCSS		40			ns
SCLK Rise to $\overline{CS}$ Rise Hold Time	tCSH		0			ns
DIN Setup Time	tDS		40			ns
DIN Hold Time	tDH		0			ns
SCLK Rise to $\overline{CS}$ Fall Delay	tCS0		40			ns
$\overline{CS}$ Rise to SCLK Rise Hold Time	tCS1		40			ns
$\overline{CS}$ Pulse Width High	tCSW		100			ns

**Note 1:** Guaranteed from code 11 to code 4095 in unity-gain configuration.

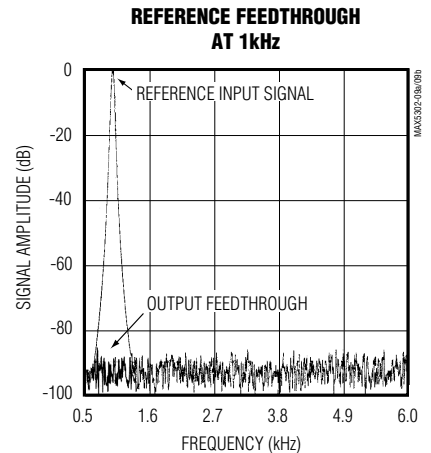
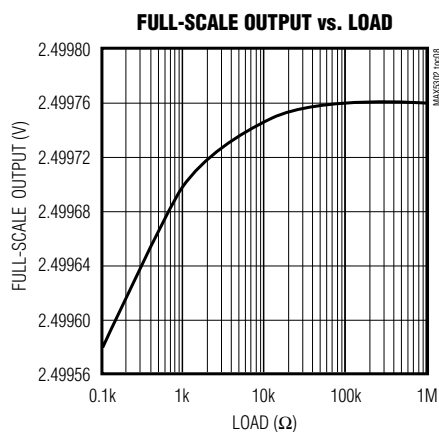
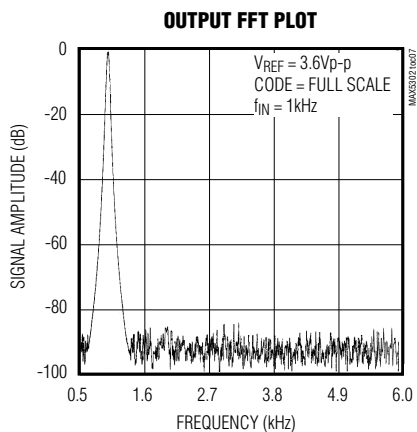
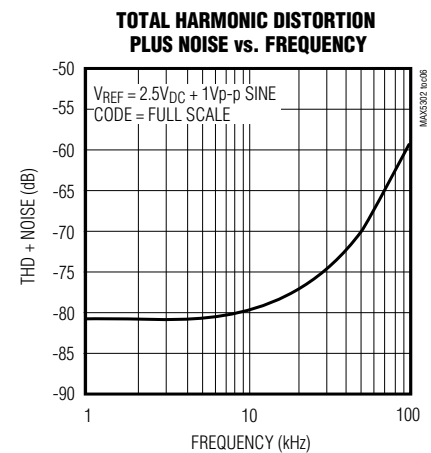
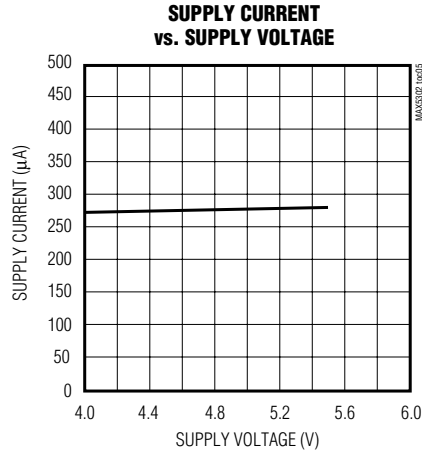
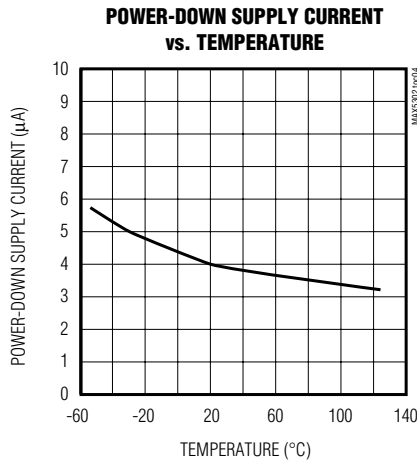
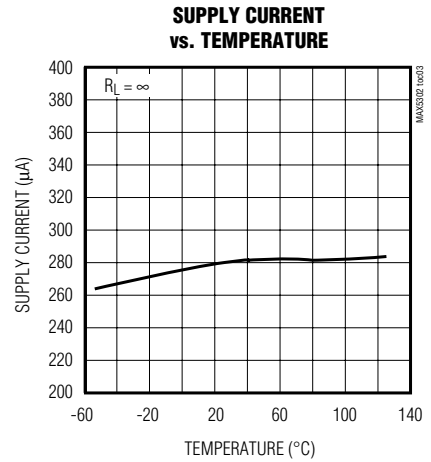
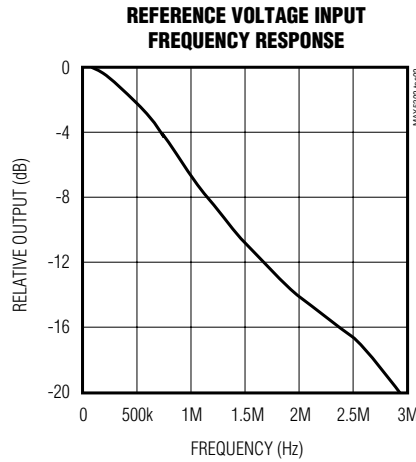
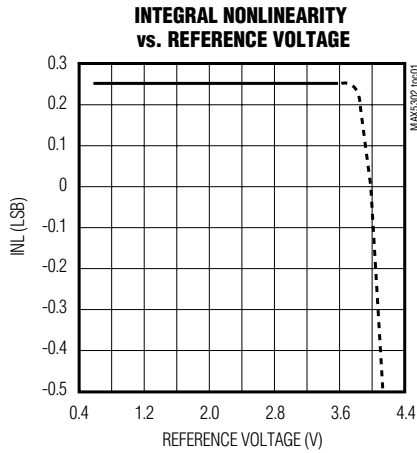
**Note 2:** Accuracy is better than 1LSB for  $V_{OUT} = 8mV$  to  $(V_{DD} - 100mV)$ , guaranteed by a power-supply rejection test at the end points.

**Note 3:**  $R_L = \infty$ , digital inputs at GND or  $V_{DD}$ .

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

## Typical Operating Characteristics

( $V_{DD} = +5V$ ,  $R_L = 5k\Omega$ ,  $C_L = 100pF$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)



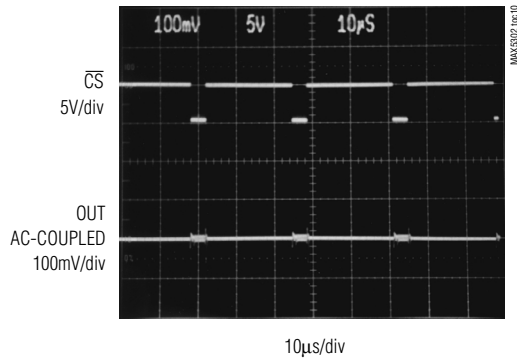
# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

MAX5302

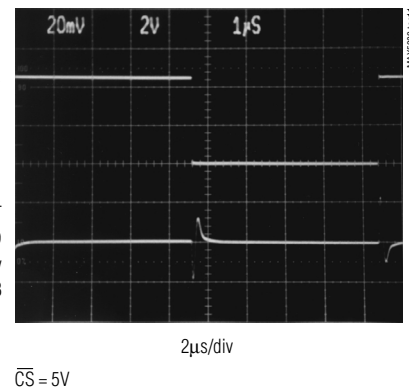
## Typical Operating Characteristics (continued)

( $V_{DD} = +5V$ ,  $R_L = 5k\Omega$ ,  $C_L = 100pF$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)

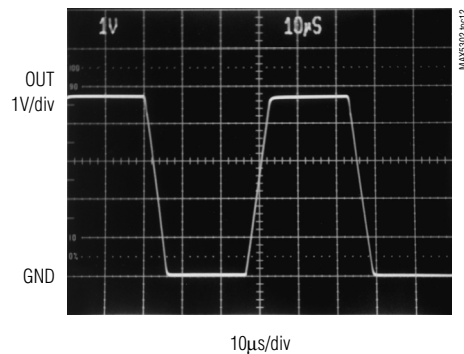
### MAJOR-CARRY TRANSITION



### DIGITAL FEEDTHROUGH ( $f_{SCLK} = 100kHz$ )



### DYNAMIC RESPONSE



GAIN = 2, SWITCHING FROM CODE 0 TO 4020

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

## Pin Description

PIN	NAME	FUNCTION
1	OUT	DAC Output Voltage
2	$\overline{\text{CS}}$	Chip-Select Input. Active low.
3	DIN	Serial-Data Input
4	SCLK	Serial-Clock Input
5	FB	DAC Output Amplifier Feedback
6	REF	Reference Voltage Input
7	GND	Ground
8	V <sub>DD</sub>	Positive Power Supply

## Detailed Description

The MAX5302 contains a voltage-output digital-to-analog converter (DAC) that is easily addressed using a simple 3-wire serial interface. The IC includes a 16-bit shift register, and has a double-buffered input composed of an input register and a DAC register (see *Functional Diagram*). In addition to the voltage output, the amplifier's negative input is available to the user.

The DAC is an inverted R-2R ladder network that converts a digital input (12 data bits plus 1 sub-bit) into an equivalent analog output voltage in proportion to the applied reference voltage. Figure 1 shows a simplified circuit diagram of the DAC.

### Reference Inputs

The reference input accepts positive DC and AC signals. The voltage at the reference input sets the full-scale output voltage for the DAC. The reference input voltage range is 0 to (V<sub>DD</sub> - 1.4V). The output voltage (V<sub>OUT</sub>) is represented by a digitally programmable voltage source, as expressed in the following equation:

$$V_{\text{OUT}} = (V_{\text{REF}} \cdot \text{NB} / 4096) \text{ Gain}$$

where NB is the numeric value of the DAC's binary input code (0 to 4095), V<sub>REF</sub> is the reference voltage, and Gain is the externally set voltage gain.

The impedance at the reference input is code dependent, ranging from a low value of 14k $\Omega$  when the DAC has an input code of 1554 hex, to a high value exceeding several gigaohms (leakage currents) with an input code of 0000 hex. Because the input impedance at the reference pin is code dependent, load regulation of the reference source is important.

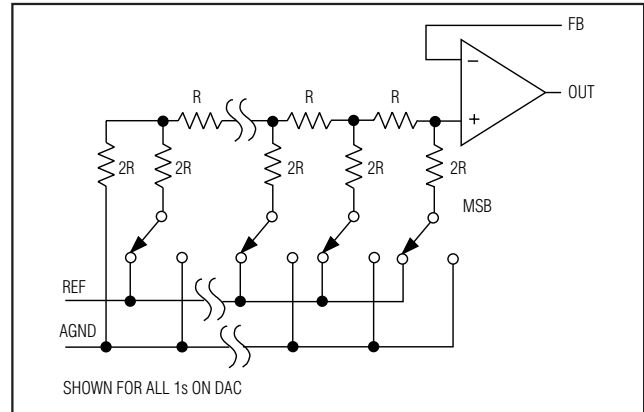


Figure 1. Simplified DAC Circuit Diagram

In shutdown mode, the MAX5302's REF input enters a high-impedance state with a typical input leakage current of 0.001 $\mu$ A.

The reference input capacitance is also code dependent and typically ranges from 15pF (with an input code of all 0s) to 50pF (at full scale).

The MAX873 +2.5V reference is recommended for the MAX5302.

### Output Amplifier

The MAX5302's DAC output is internally buffered by a precision amplifier with a typical slew rate of 0.6V/ $\mu$ s. Access to the output amplifier's inverting input provides the user greater flexibility in output gain setting/signal conditioning (see the *Applications Information* section).

With a full-scale transition at the MAX5302 output, the typical settling time to  $\pm 1/2$ LSB is 14 $\mu$ s when loaded with 5k $\Omega$  in parallel with 100pF (loads less than 2k $\Omega$  degrade performance).

The amplifier's output dynamic responses and settling performances are shown in the *Typical Operating Characteristics*.

### Shutdown Mode

The MAX5302 features a software-programmable shutdown that reduces supply current to a typical value of 4 $\mu$ A. Writing 11X XXXX XXXX XXXX as the input control word puts the device in shutdown mode (Table 1).

In shutdown mode, the amplifier's output and the reference input enter a high-impedance state. The serial interface remains active. Data in the input registers is retained in shutdown, allowing the MAX5302 to recall the output state prior to entering shutdown. Exit shutdown mode by either recalling the previous configuration or

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

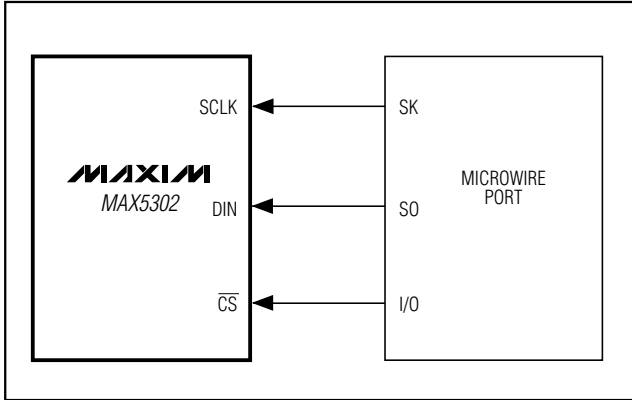


Figure 2. Connections for MICROWIRE

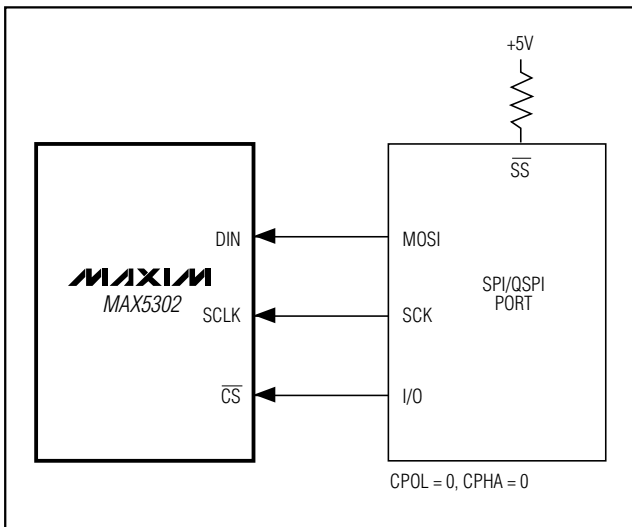


Figure 3. Connections for SPI/QSPI

by updating the DAC with new data. When powering up the device or bringing it out of shutdown, allow 20µs for the output to stabilize.

### Serial-Interface Configurations

The MAX5302's 3-wire serial interface is compatible with both MICROWIRE (Figure 2) and SPI/QSPI (Figure 3). The serial-input word consists of 3 control bits followed by 12+1 data bits (MSB first), as shown in Figure 4. The 3-bit control code determines the MAX5302's response outlined in Table 1.

The MAX5302's digital inputs are double buffered. Depending on the command issued through the serial interface, the input register can be loaded without affecting the DAC register, the DAC register can be loaded directly, or the DAC register can be updated from the input register (Table 1).

### Serial-Interface Description

The MAX5302 requires 16 bits of serial data. Table 1 lists the serial-interface programming commands. For certain commands, the 12+1 data bits are "don't cares." Data is sent MSB first and can be sent in two 8-bit packets or one 16-bit word ( $\overline{CS}$  must remain low until 16 bits are transferred). The serial data is composed of 3 control

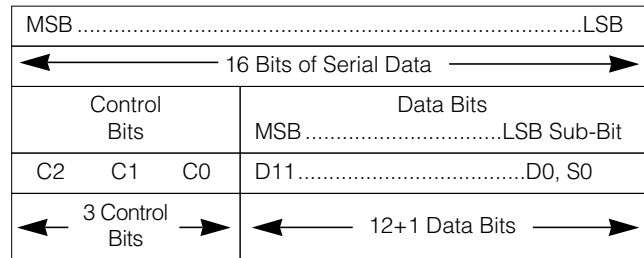


Figure 4. Serial-Data Format

Table 1. Serial-Interface Programming Commands

16-BIT SERIAL WORD					FUNCTION
C2	C1	C0	D11.....D0 MSB      LSB	S0	
X	0	0	12 bits of data	0	Load input register; DAC register immediately updated (also exit shutdown).
X	0	1	12 bits of data	0	Load input register; DAC register unchanged.
X	1	0	XXXXXXXXXXXX	X	Update DAC register from input register (also exit shutdown; recall previous state).
1	1	1	XXXXXXXXXXXX	X	Shutdown
0	1	1	XXXXXXXXXXXX	X	No operation (NOP)

X = Don't care

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

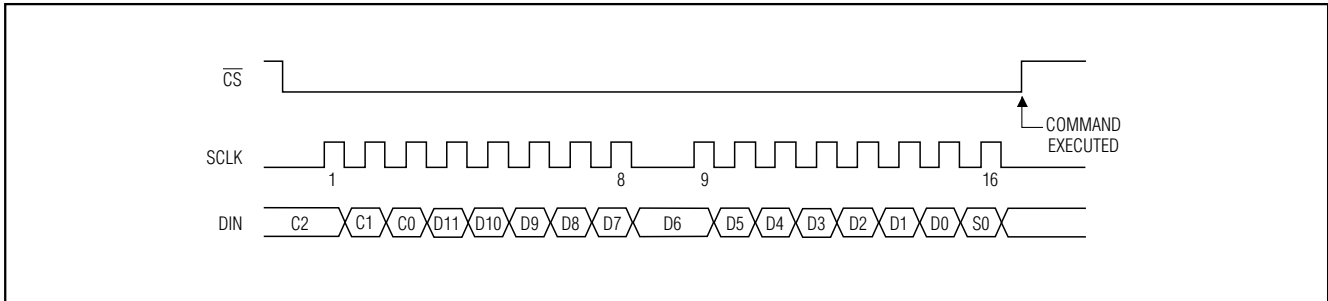


Figure 5. Serial-Interface Timing Diagram

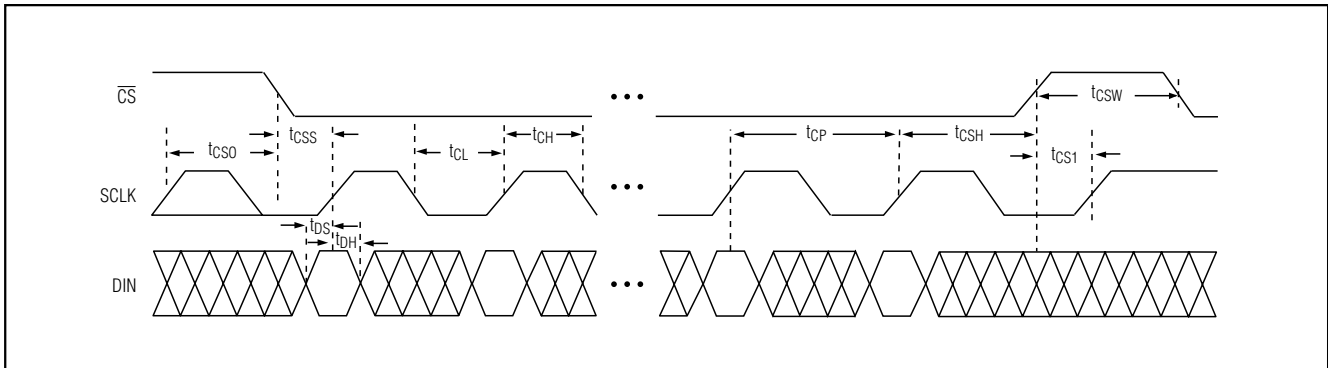


Figure 6. Detailed Serial-Interface Timing Diagram

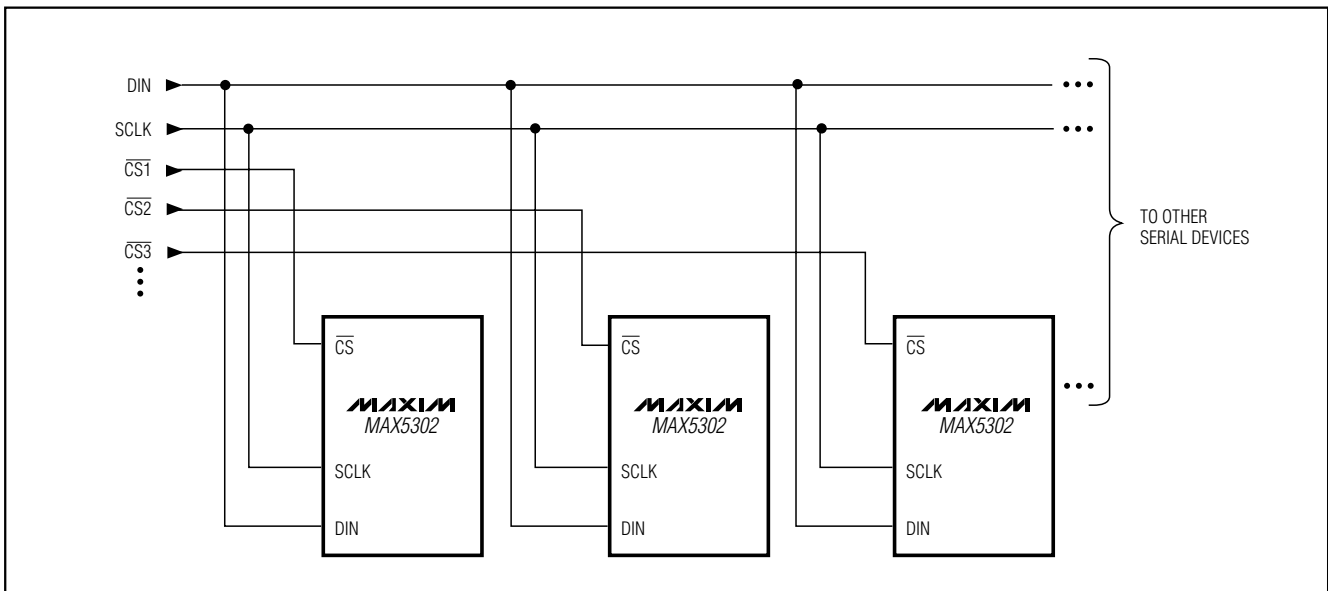


Figure 7. Multiple MAX5302s Sharing Common DIN and SCLK Lines



# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

bits (C2, C1, C0), followed by the 12+1 data bits D11...D0, S0 (Figure 4). Set the sub-bit (S0) to zero. The 3-bit control code determines the register to be updated and the configuration when exiting shutdown.

Figures 5 and 6 show the serial-interface timing requirements. The chip-select ( $\overline{CS}$ ) pin must be low to enable the DAC's serial interface. When  $\overline{CS}$  is high, the interface control circuitry is disabled.  $\overline{CS}$  must go low at least  $t_{CSS}$  before the rising serial-clock (SCLK) edge to properly clock in the first bit. When  $\overline{CS}$  is low, data is clocked into the internal shift register through the serial-data input pin (DIN) on SCLK's rising edge. The maximum guaranteed clock frequency is 10MHz. Data is latched into the MAX5302 input/DAC register on  $\overline{CS}$ 's rising edge.

Figure 7 shows a method of connecting several MAX5302s. In this configuration, the clock and the data bus are common to all devices, and separate chip-select lines are used for each IC.

## Applications Information

### Unipolar Output

For a unipolar output, the output voltage and the reference input have the same polarity. Figure 8 shows the MAX5302 unipolar output circuit, which is also the typical operating circuit. Table 2 lists the unipolar output codes.

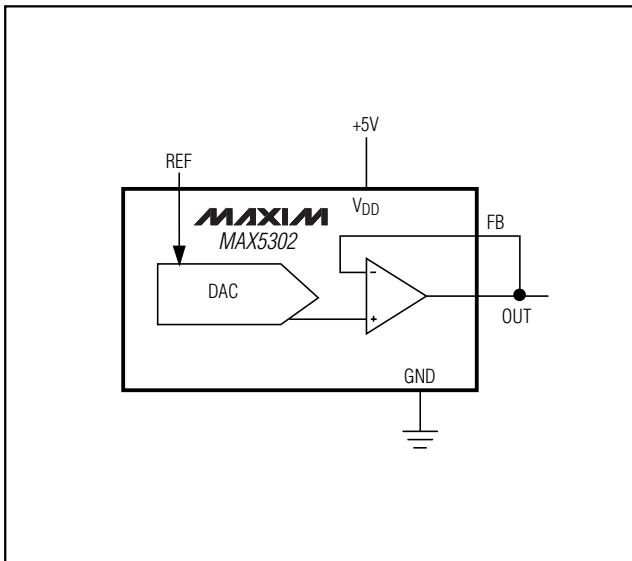


Figure 8. Unipolar Output Circuit

Rail-to-Rail is a registered trademark of Nippon Motorola, Ltd.



Figure 9 illustrates a Rail-to-Rail<sup>®</sup> output. This circuit shows the MAX5302 with the output amplifier configured with a closed-loop gain of +2 to provide a 0V to 5V full-scale range when a 2.5V reference is used.

### Bipolar Output

The MAX5302 output can be configured for bipolar operation using Figure 10's circuit according to the following equation:

$$V_{OUT} = V_{REF} [(2NB / 4096) - 1]$$

where NB is the numeric value of the DAC's binary input code. Table 3 shows digital codes (offset binary) and the corresponding output voltage for Figure 10's circuit.

### Using an AC Reference

In applications where the reference has AC-signal components, the MAX5302 has multiplying capability within the reference input range specifications. Figure 11 shows a technique for applying a sine-wave signal to the reference input where the AC signal is offset before being applied to REF. The reference voltage must never be more negative than GND.

The MAX5302's total harmonic distortion plus noise (THD+N) is typically less than -77dB (full-scale code), given a 1Vp-p signal swing and input frequencies up to 25kHz. The typical -3dB frequency is 650kHz, as shown in the *Typical Operating Characteristics* graphs.

Table 2. Unipolar Code Table

DAC CONTENTS MSB	LSB	ANALOG OUTPUT
1111	1111 (0)	$+V_{REF} \left( \frac{4095}{4096} \right)$
1000	0000 0001 (0)	$+V_{REF} \left( \frac{2049}{4096} \right)$
1000	0000 0000 (0)	$+V_{REF} \left( \frac{2048}{4096} \right) = \frac{+V_{REF}}{2}$
0111	1111 (0)	$+V_{REF} \left( \frac{2047}{4096} \right)$
0000	0000 0001 (0)	$+V_{REF} \left( \frac{1}{4096} \right)$
0000	0000 0000 (0)	0V

Note: ( ) are for sub-bit.

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

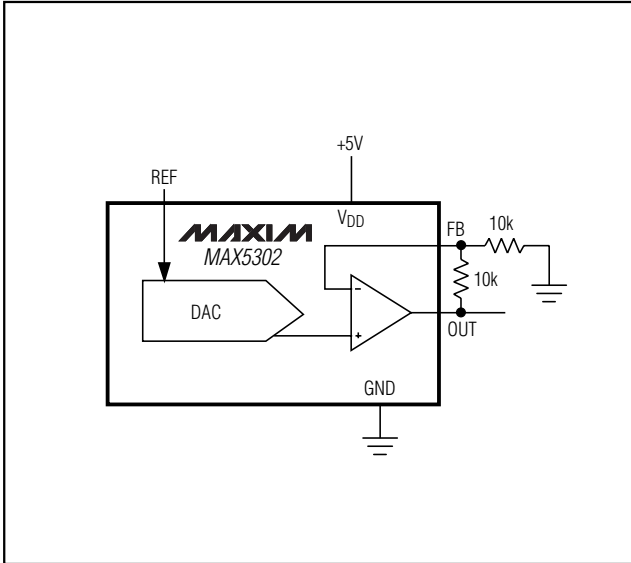


Figure 9. Unipolar Rail-to-Rail Output Circuit

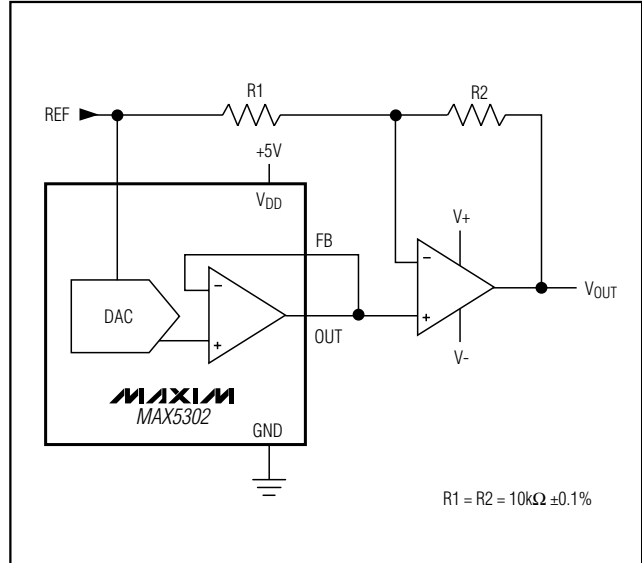


Figure 10. Bipolar Output Circuit

### Digitally Programmable Current Source

The circuit of Figure 12 places an NPN transistor (2N3904 or similar) within the op amp feedback loop to implement a digitally programmable, unidirectional current source. The output current is calculated with the following equation:

$$I_{OUT} = (V_{REF} / R) (NB / 4096)$$

where NB is the numeric value of the DAC's binary input code, and R is the sense resistor shown in Figure 12.

### Power-Supply Considerations

On power-up, the input and DAC registers are cleared (set to zero code).

For rated MAX5302 performance,  $V_{REF}$  must be at least 1.4V below  $V_{DD}$ . Bypass  $V_{DD}$  with a 4.7 $\mu$ F capacitor in parallel with a 0.1 $\mu$ F capacitor to GND. Use short lead lengths and place the bypass capacitors as close to the supply pins as possible.

### Grounding and Layout Considerations

Digital or AC transient signals on GND can create noise at the analog output. Connect GND to the highest-quality ground available.

Good PC board ground layout minimizes crosstalk between the DAC output, reference input, and digital input. Reduce crosstalk by keeping analog lines away from digital lines. Wire-wrapped boards are not recommended.

Table 3. Bipolar Code Table

DAC CONTENTS		ANALOG OUTPUT
MSB	LSB	
1111	1111 1111 (0)	$+V_{REF} \left( \frac{2047}{2048} \right)$
1000	0000 0001 (0)	$+V_{REF} \left( \frac{1}{2048} \right)$
1000	0000 0000 (0)	0V
0111	1111 1111 (0)	$-V_{REF} \left( \frac{1}{2048} \right)$
0000	0000 0001 (0)	$-V_{REF} \left( \frac{2047}{2048} \right)$
0000	0000 0000 (0)	$-V_{REF} \left( \frac{2048}{2048} \right) = -V_{REF}$

Note: ( ) are for sub-bit.

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

MAX5302

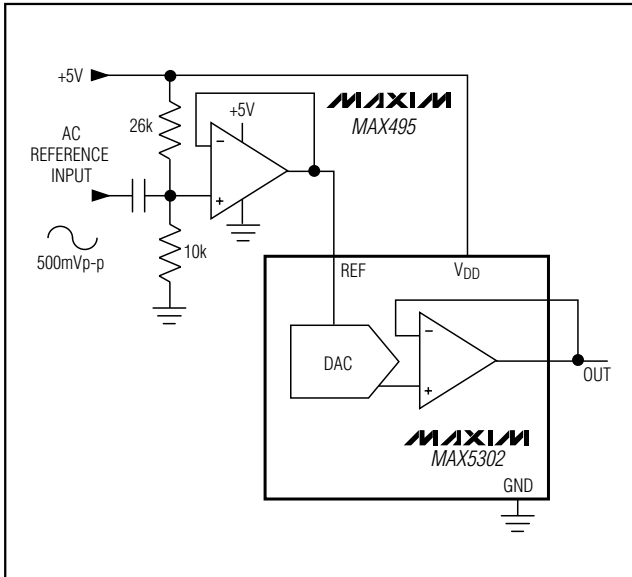


Figure 11. AC Reference Input Circuit

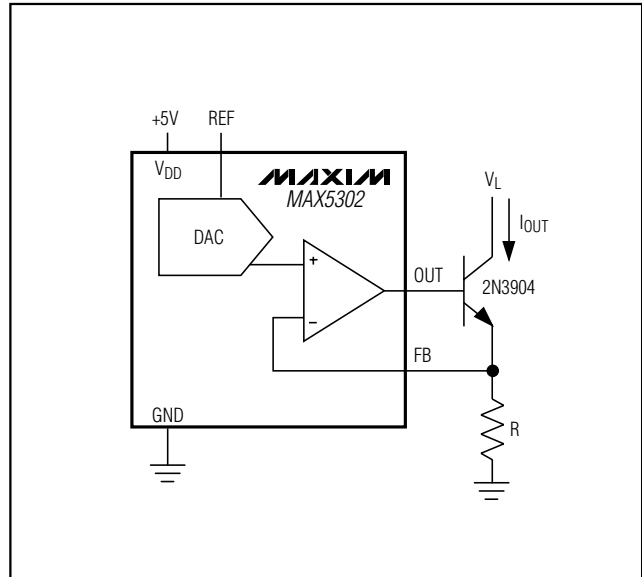


Figure 12. Digitally Programmable Current Source

## Chip Information

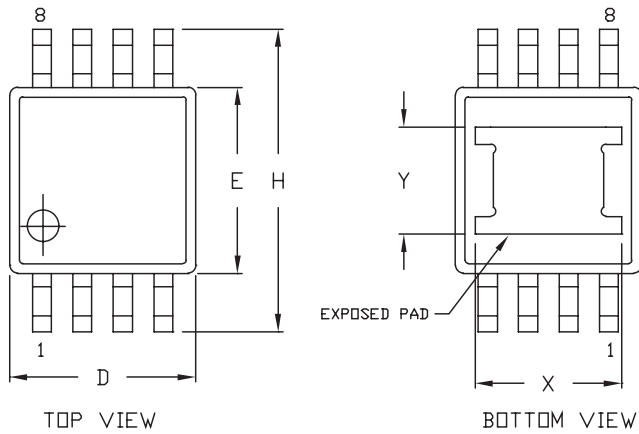
TRANSISTOR COUNT: 3053

SUBSTRATE CONNECTED TO AGND

# Low-Power, 12-Bit Voltage-Output DAC with Serial Interface

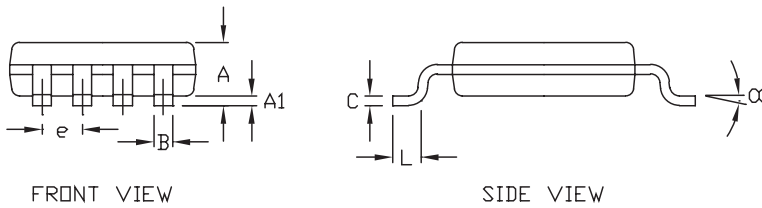
## Package Information

8LUMAXDLEFS



	INCHES		MILLIMETERS		JEDEC			
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
A	0.037	0.043	0.94	1.10	---	0.043	---	1.10
A1	0.002	0.006	0.05	0.15	0.002	0.006	0.05	0.15
B	0.010	0.014	0.25	0.36	0.010	0.016	0.25	0.40
C	0.005	0.007	0.13	0.18	0.005	0.009	0.13	0.23
D	0.116	0.120	2.95	3.05	0.114	0.122	2.9	3.1
e	0.0256 BSC		0.65 BSC		0.0256 BSC		0.64 BSC	
E	0.116	0.120	2.95	3.05	0.114	0.122	2.9	3.1
H	0.188	0.198	4.78	5.03	0.193 BSC		4.9 BSC	
L	0.016	0.026	0.41	0.66	0.016	0.027	0.40	0.70
α	0°	6°	0°	6°	0°	6°	0°	6°
*X	0.087	0.099	2.210	2.515				
*Y	0.062	0.074	1.575	1.880				

\* EXPOSED PAD



- NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH.
  2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15 MM (.006").
  3. CONTROLLING DIMENSION: MILLIMETERS.
  4. MEETS JEDEC MO-187.
  5. DIMENSIONS X & Y APPLY TO EXPOSED PAD VERSIONS ONLY.
  6. EXPOSED PAD FLUSH WITH BOTTOM OF PACKAGE WITHIN .002".

<b>MAXIM</b>		
<small>PROPRIETARY INFORMATION</small>		
<small>TITLE:</small>		
PACKAGE OUTLINE, 8L uMAX		
<small>APPROVAL</small>	<small>DOCUMENT CONTROL NO.</small>	<small>REV</small>
	21-0036	G 1/1

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