19-1562; Rev 0; 10/99

MAXIM

10-Bit Voltage-Output DAC in 8-Pin µMAX

MAX5304

General Description

The MAX5304 combines a low-power, voltage-output, 10-bit digital-to-analog converter (DAC) and a precision output amplifier in an 8-pin µMAX package. It operates from a single +5V supply, drawing less than 280µA 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 MAX5304 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.

Features

- **10-Bit DAC with Configurable Output Amplifier**
- **+5V Single-Supply Operation**
- **Low Supply Current**
  0.28mA Normal Operation
  2µA Shutdown Mode
- **Available in 8-Pin µMAX**
- **Power-On Reset Clears DAC Output to Zero**
- **SPI/QSPI/MICROWIRE Compatible**
- **Schmitt-Trigger Digital Inputs for Direct Optocoupler Interface**

Applications

Digital Offset and Gain Adjustment

Industrial Process Control

Microprocessor-Controlled Systems

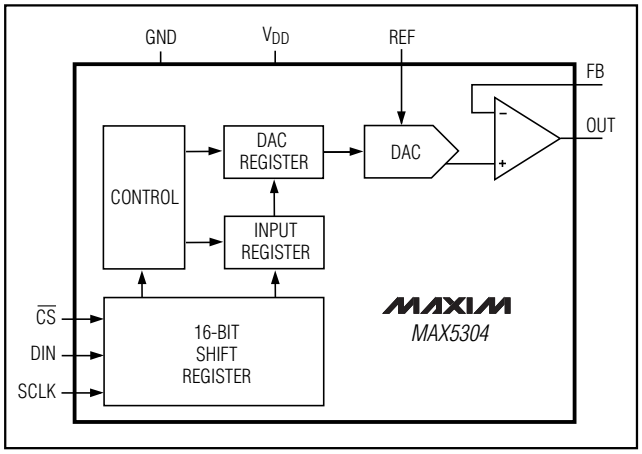
Portable Test Instruments

Remote Industrial Control

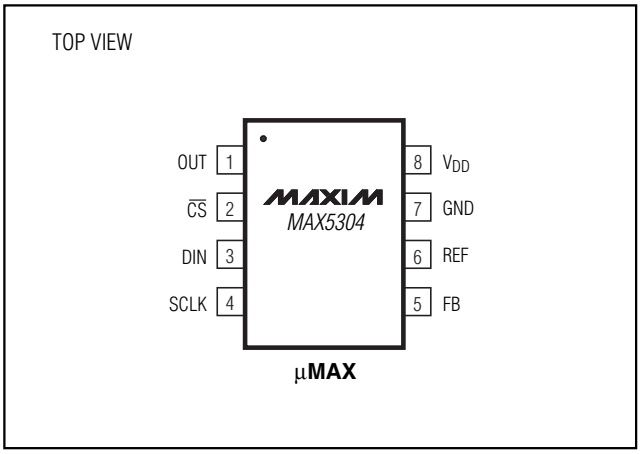
Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX5304CUA	0°C to +70°C	8 µMAX
MAX5304EUA	-40°C to +85°C	8 µMAX

Functional Diagram



Pin Configuration



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

10-Bit Voltage-Output DAC in 8-Pin µMAX

ABSOLUTE MAXIMUM RATINGS

V_{DD} to GND.....-0.3V to +6V
REF, OUT, FB to GND.....-0.3V to (V_{DD} + 0.3V)
Digital Inputs to GND.....-0.3V to +6V
Continuous Current into Any Pin.....±20mA
Continuous Power Dissipation (T_A = +70°C)
8-Pin µMAX (derate 4.10mW/°C above+70°C).....330mW

Operating Temperature Ranges
MAX5304CUA.....0°C to +70°C
MAX5304EUA.....-40°C to +85°C
Junction Temperature.....+150°C
Storage Temperature Range.....-65°C to +150°C
Lead Temperature (soldering, 10s)..... .....+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_{DD} = +5V ±10%, V_{REF} = +2.5V, R_L = 5kΩ, C_L = 100pF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C. Output buffer connected in unity-gain configuration.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
STATIC PERFORMANCE—ANALOG SECTION						
Resolution	N		10			Bits
Differential Nonlinearity	DNL	Guaranteed monotonic			±1.0	LSB
Integral Nonlinearity (Note 1)	INL				±4	LSB
Offset Error	V_{OS}			±0.3	±8	mV
Offset-Error Tempco	TCV_{OS}			6		ppm/°C
Gain Error (Note 1)	GE			-0.3	±2	LSB
Gain-Error Tempco				1		ppm/°C
Power-Supply Rejection Ratio	PSRR	4.5V ≤ V_{DD} ≤ 5.5V			800	µV/V
REFERENCE INPUT						
Reference Input Range	V_{REF}		0		V_{DD} - 1.4	V
Reference Input Resistance	R_{REF}	Code dependent, minimum at code 1550 hex	18	30		kΩ
MULTIPLYING-MODE PERFORMANCE						
Reference -3dB Bandwidth		V_{REF} = 0.67Vp-p		650		kHz
Reference Feedthrough		Input code = all 0s, V_{REF} = 3.6Vp-p at 1kHz		-84		dB
Signal-to-Noise Plus Distortion Ratio	SINAD	V_{REF} = 1Vp-p at 25kHz, code = full scale		77		dB
DIGITAL INPUTS						
Input High Voltage	V_{IH}		2.4			V
Input Low Voltage	V_{IL}				0.8	V
Input Leakage Current	I_{IN}	V_{IN} = 0 or V_{DD}		0.001	±0.5	µA
Input Capacitance	C_{IN}			8		pF

ELECTRICAL CHARACTERISTICS (continued)

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

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
DYNAMIC PERFORMANCE						
Voltage Output Slew Rate	SR			0.6		V/µs
Output Settling Time		To ±1/2LSB, V_{STEP} = 2.5V		10		µs
Output Voltage Swing		Rail-to-rail (Note 2)		0 to V_{DD}		V
Current into FB				0.001	±0.1	µA
Start-Up Time				20		µs
Digital Feedthrough		$\overline{CS}$ = V_{DD}, DIN = 100kHz		5		nVs
POWER SUPPLIES						
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	µA
Reference Current in Shutdown				0.001	±0.5	µA
TIMING CHARACTERISTICS (Figure 6)						
SCLK Clock Period	t_{CP}		100			ns
SCLK Pulse Width High	t_{CH}		40			ns
SCLK Pulse Width Low	t_{CL}		40			ns
$\overline{CS}$ Fall to SCLK Rise Setup Time	t_{CSS}		40			ns
SCLK Rise to $\overline{CS}$ Rise Hold Time	t_{CSH}		0			ns
DIN Setup Time	t_{DS}		40			ns
DIN Hold Time	t_{DH}		0			ns
SCLK Rise to $\overline{CS}$ Fall Delay	t_{CS0}		40			ns
$\overline{CS}$ Rise to SCLK Rise Hold Time	t_{CS1}		40			ns
$\overline{CS}$ Pulse Width High	t_{CSW}		100			ns

Note 1: Guaranteed from code 3 to code 1023 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.

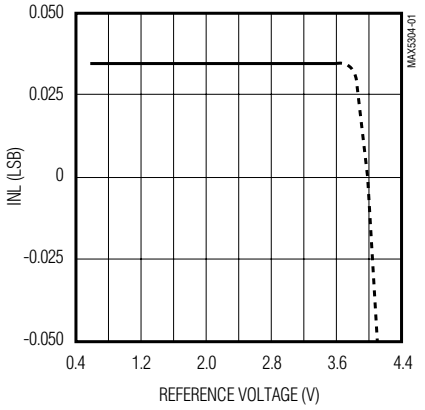
Note 3: R_L = ∞, digital inputs at GND or V_{DD}.

10-Bit Voltage-Output DAC in 8-Pin µMAX

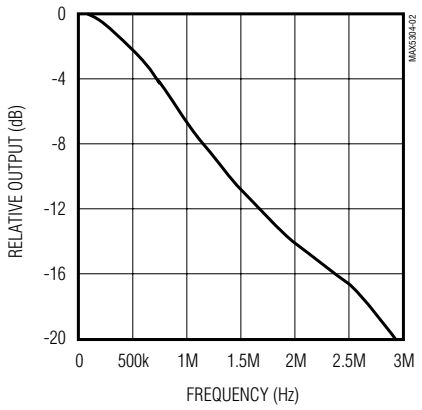
Typical Operating Characteristics

(V_{DD} = +5V, R_L = 5kΩ, C_L = 100pF, T_A = +25°C, unless otherwise noted.)

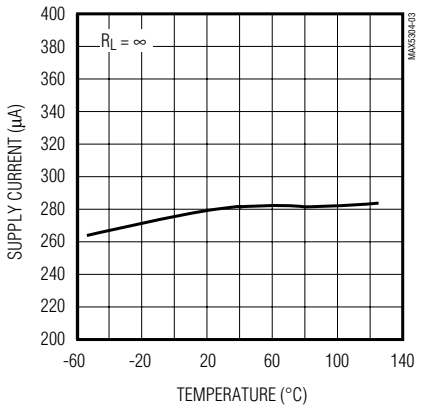
INTEGRAL NONLINEARITY vs. REFERENCE VOLTAGE



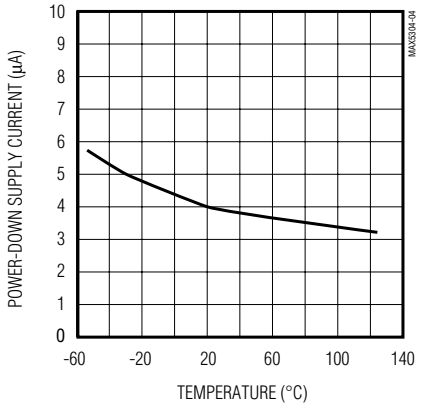
REFERENCE VOLTAGE INPUT FREQUENCY RESPONSE



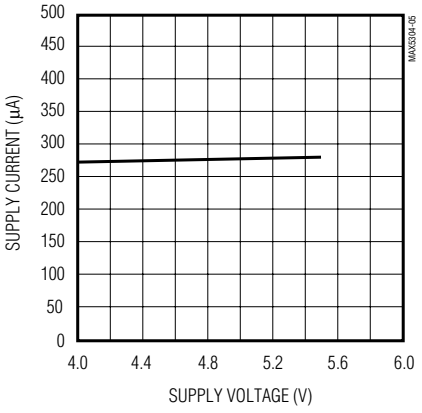
SUPPLY CURRENT vs. TEMPERATURE



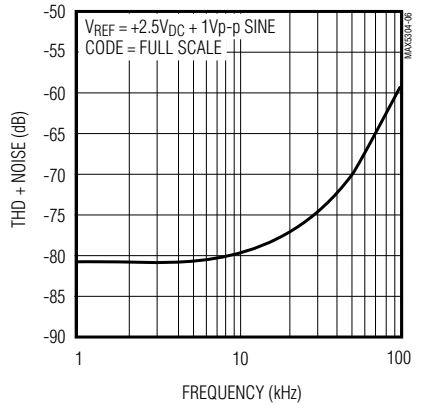
POWER-DOWN SUPPLY CURRENT vs. TEMPERATURE



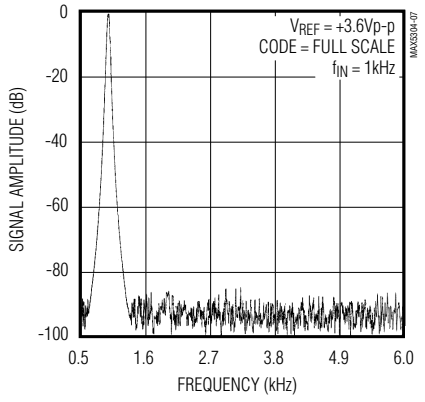
SUPPLY CURRENT vs. SUPPLY VOLTAGE



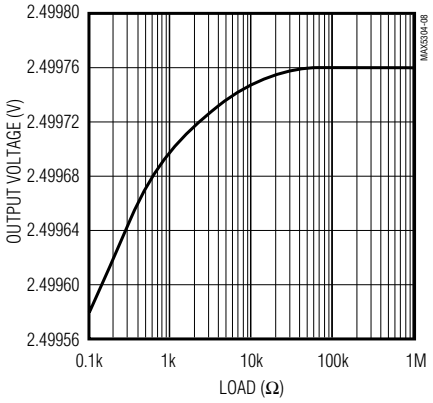
TOTAL HARMONIC DISTORTION PLUS NOISE vs. FREQUENCY



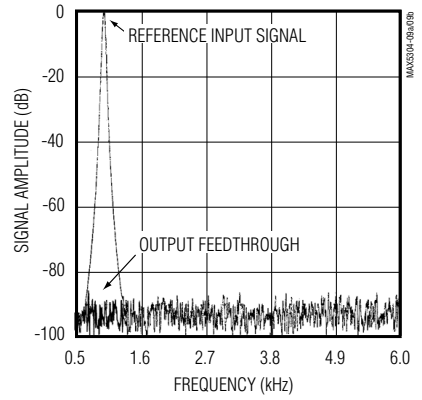
OUTPUT FFT PLOT



OUTPUT VOLTAGE vs. LOAD



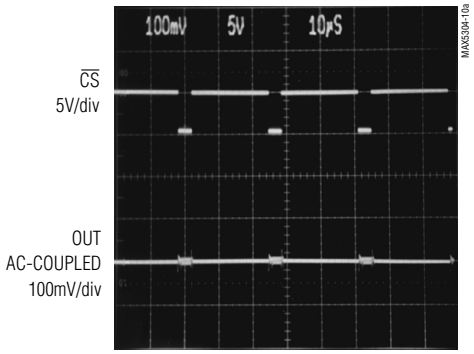
REFERENCE FEEDTHROUGH AT 1kHz



Typical Operating Characteristics (continued)

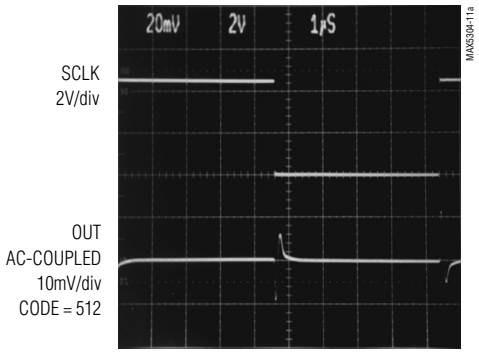
(V_{DD} = +5V, R_L = 5kΩ, C_L = 100pF, T_A = +25°C, unless otherwise noted.)

MAJOR-CARRY TRANSITION



10µs/div

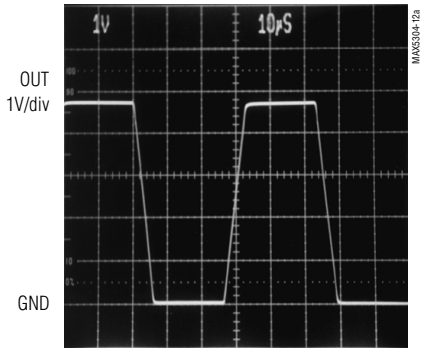
DIGITAL FEEDTHROUGH (f_{SCLK} = 100kHz)



2µs/div

CS = 5V

DYNAMIC RESPONSE



10µs/div

GAIN = +2V/V, SWITCHING FROM CODE 0 TO 1005

10-Bit Voltage-Output DAC in 8-Pin µMAX

Pin Description

PIN	NAME	FUNCTION
1	OUT	DAC Output Voltage
2	$\overline{CS}$	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_{DD}	Positive Power Supply

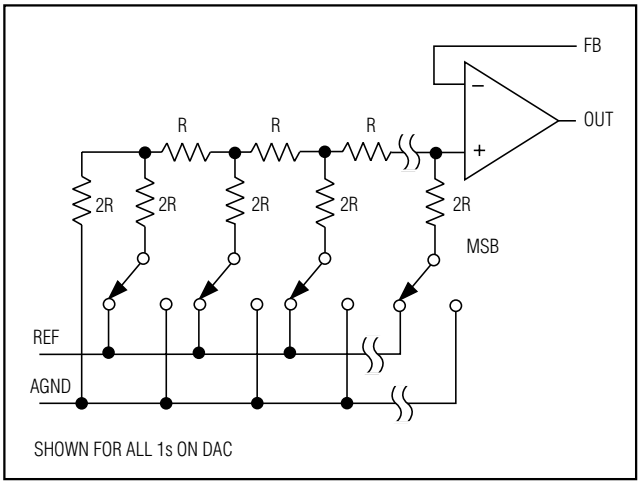


Figure 1. Simplified DAC Circuit Diagram

Detailed Description

The MAX5304 contains a voltage-output digital-to-analog converter (DAC) that is easily addressed using a simple 3-wire serial interface. Each IC includes a 16-bit shift register, and has a double-buffered input composed of an input register and a DAC register (see the *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 (10 data bits plus 3 sub-bits) 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 0V to (V_{DD} - 1.4V). The output voltage (V_{OUT}) is represented by a digitally programmable voltage source, as expressed in the following equation:

$$V_{OUT} = (V_{REF} \cdot NB / 1024)\ Gain$$

where NB is the numeric value of the DAC's binary input code (0 to 1023), V_{REF} 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 18kΩ when the DAC has an input code of 1550 hex, to a high value exceeding several gigohms (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.

In shutdown mode, the MAX5304's REF input enters a high-impedance state with a typical input leakage current of 0.001µA.

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 use with the MAX5304.

Output Amplifier

The MAX5304's DAC output is internally buffered by a precision amplifier with a typical slew rate of 0.6V/µs. 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 MAX5304 output, the typical settling time to ±1/2LSB is 10µs when loaded with 5kΩ in parallel with 100pF (loads less than 2kΩ degrade performance).

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

Shutdown Mode

The MAX5304 features a software-programmable shutdown that reduces supply current to a typical value of 4µA. Writing 111X 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 register is retained in shutdown, allowing the MAX5304 to recall the output state prior to entering shutdown. Exit shutdown mode by either recalling the previous configuration or updating the DAC with new data. When powering up the device or bringing it out of shutdown, allow 20µs for the outputs to stabilize.

Serial-Interface Configurations

The MAX5304's 3-wire serial interface is compatible with MICROWIRE (Figure 2) and SPI/QSPI (Figure 3). The serial-input word consists of three control bits followed by 10+3 data bits (MSB first), as shown in Figure 4. The 3-bit control code determines the MAX5304's response outlined in Table 1.

The MAX5304'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 MAX5304 requires 16 bits of serial data. Table 1 lists the serial-interface programming commands. For certain commands, the 10+3 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 three control bits (C2, C1, C0), followed by the 10+3 data bits D9...D0, S2, S1, S0 (Figure 4). Set the sub-bits (S2, S1, S0) to zero. The 3-bit control code determines the register to be updated and the configuration when exiting shutdown.

Figure 5 shows the serial-interface timing requirements. The chip-select pin ($\overline{CS}$) 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 MAX5304 input/DAC register on $\overline{CS}$'s rising edge.

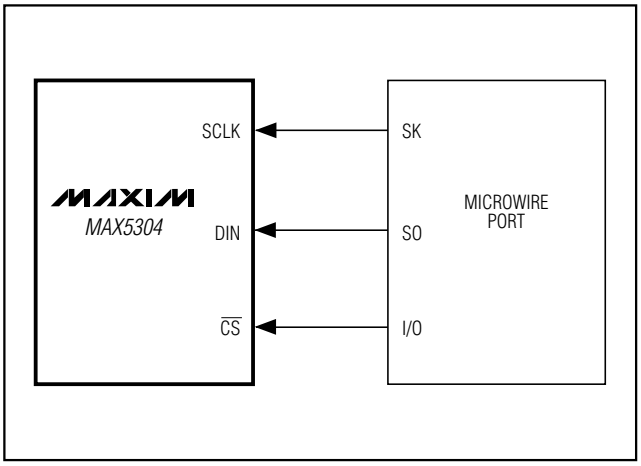


Figure 2. Connections for MICROWIRE

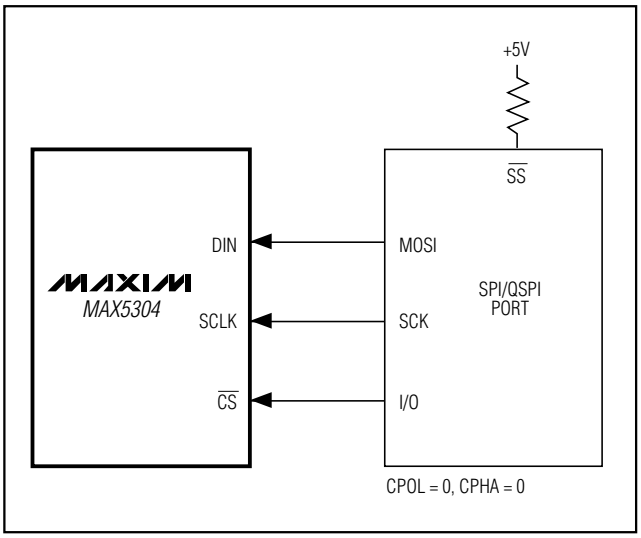


Figure 3. Connections for SPI/QSPI

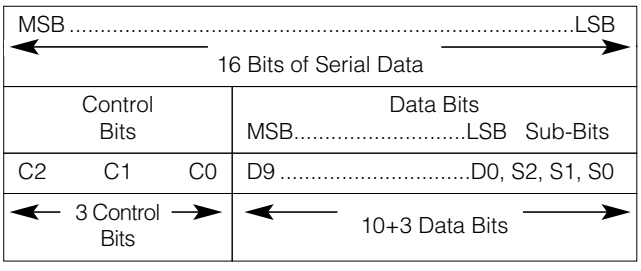


Figure 4. Serial-Data Format

10-Bit Voltage-Output DAC in 8-Pin µMAX

Table 1. Serial-Interface Programming Commands

16-BIT SERIAL WORD					FUNCTION
C2	C1	C0	D9.....D0 MSB LSB	S2...S0	
X	0	0	10 bits of data	000	Load input register; DAC register immediately updated (also exit shutdown).
X	0	1	10 bits of data	000	Load input register; DAC register unchanged.
X	1	0	XXXXXXXXXX	XXX	Update DAC register from input register (also exit shutdown; recall previous state).
1	1	1	XXXXXXXXXX	XXX	Shutdown
0	1	1	XXXXXXXXXX	XXX	No operation (NOP)

X = Don't care

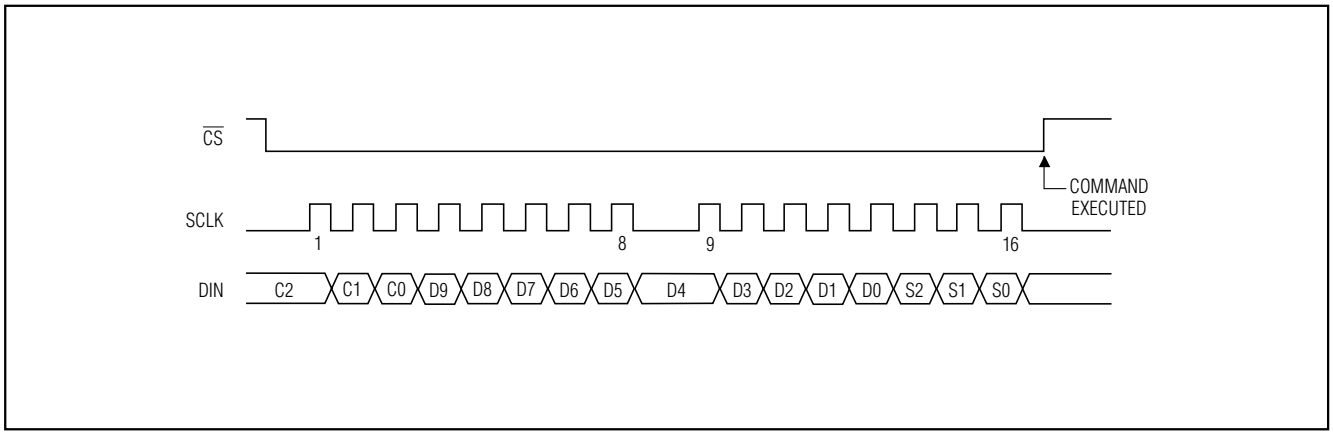


Figure 5. Serial-Interface Timing Diagram

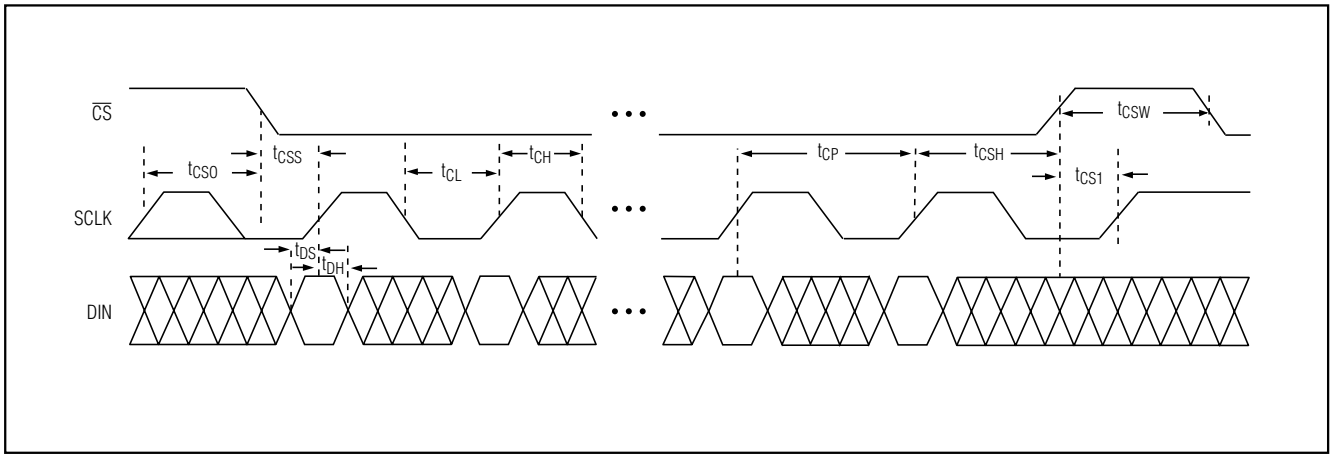


Figure 6. Detailed Serial-Interface Timing Diagram

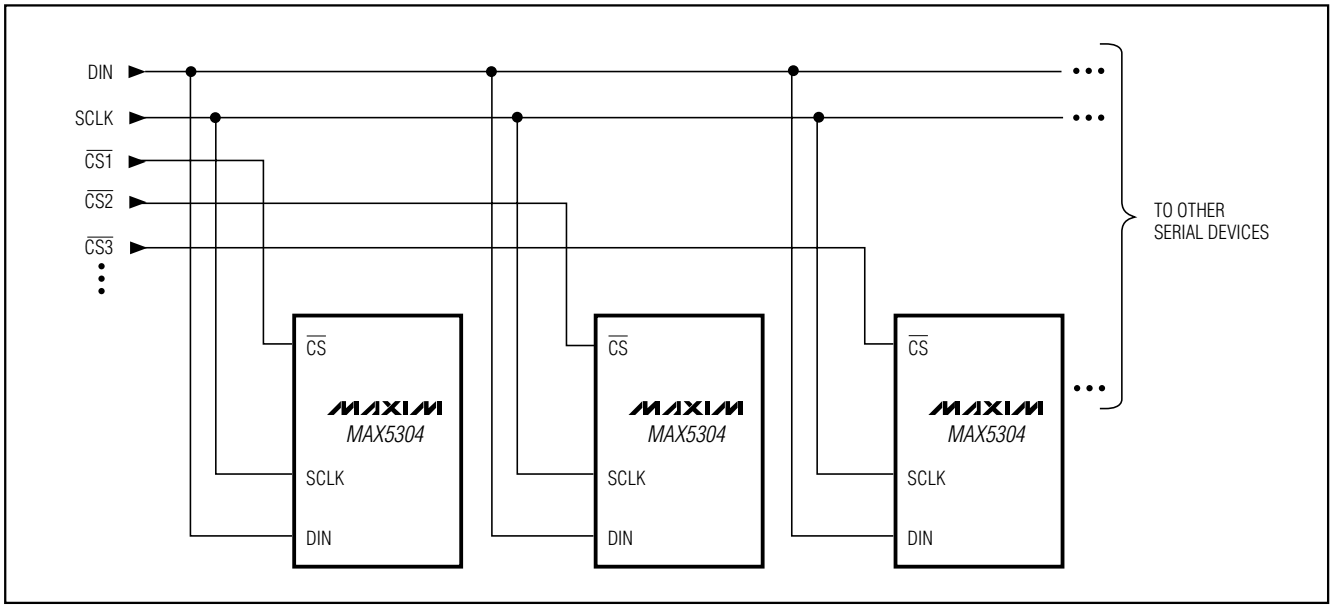


Figure 7. Multiple MAX5304s Sharing Common DIN and SCLK Lines

Figure 7 shows a method of connecting several MAX5304s. 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 MAX5304 unipolar output circuit, which is also the typical operating circuit. Table 2 lists the unipolar output codes.

Figure 9 illustrates a Rail-to-Rail® output configuration. This circuit shows the MAX5304 with the output amplifier configured for a closed-loop gain of +2V/V to provide a 0 to 5V full-scale range when a 2.5V reference is used.

Bipolar Output

The MAX5304 output can be configured for bipolar operation using Figure 10's circuit according to the following equation:

$$V_{OUT} = V_{REF} [(2NB / 1024) - 1]$$

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

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

Table 2. Unipolar Output Codes

DAC CONTENTS MSB LSB	ANALOG OUTPUT
11 1111 1111 (000)	$+V_{REF}\left(\frac{1023}{1024}\right)$
10 0000 0001 (000)	$+V_{REF}\left(\frac{513}{1024}\right)$
10 0000 0000 (000)	$+V_{REF}\left(\frac{512}{1024}\right) = \frac{+V_{REF}}{2}$
01 1111 1111 (000)	$+V_{REF}\left(\frac{511}{1024}\right)$
00 0000 0001 (000)	$+V_{REF}\left(\frac{1}{1024}\right)$
00 0000 0000 (000)	0V

Note: *( ) are for sub-bits.*

Using an AC Reference

In applications where the reference has AC signal components, the MAX5304 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.

10-Bit Voltage-Output DAC in 8-Pin µMAX

Table 3. Bipolar Output Codes

DAC CONTENTS MSB LSB	ANALOG OUTPUT
11 1111 1111 (000)	$+V_{REF}\left(\frac{511}{512}\right)$
10 0000 0001 (000)	$+V_{REF}\left(\frac{1}{512}\right)$
10 0000 0000 (000)	0V
01 1111 1111 (000)	$-V_{REF}\left(\frac{1}{512}\right)$
00 0000 0001 (000)	$-V_{REF}\left(\frac{511}{512}\right)$
00 0000 0000 (000)	$-V_{REF}\left(\frac{512}{512}\right) = -V_{REF}$

Note: *( ) are for sub-bits.*

The MAX5304'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.

Digitally Programmable Current Source

Figure 12's circuit 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:

$$I_{OUT} = (V_{REF} / R)(NB / 1024)$$

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

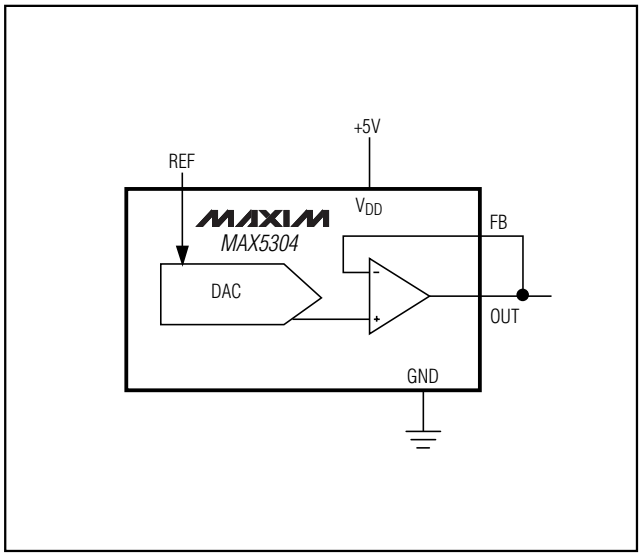


Figure 8. Unipolar Output Circuit

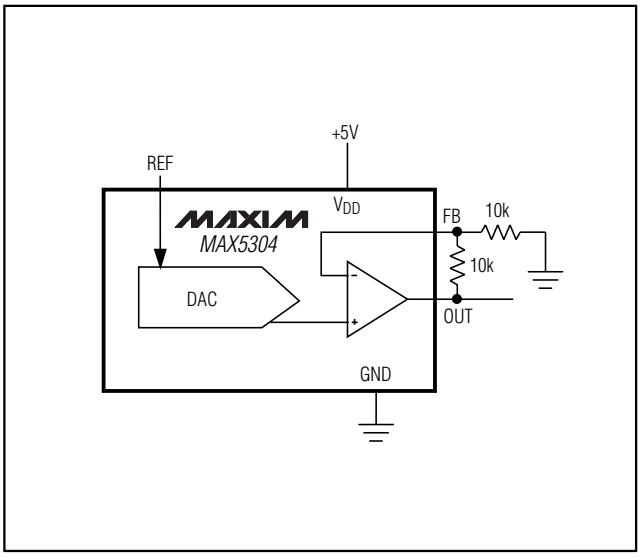


Figure 9. Unipolar Rail-to-Rail Output Circuit

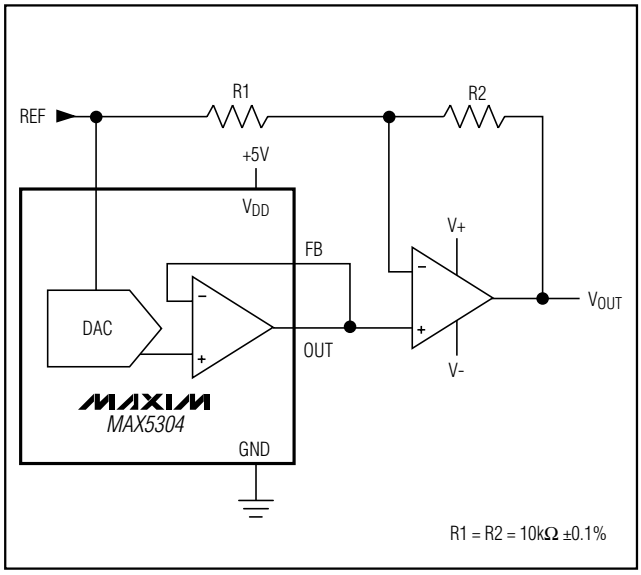


Figure 10. Bipolar Output Circuit

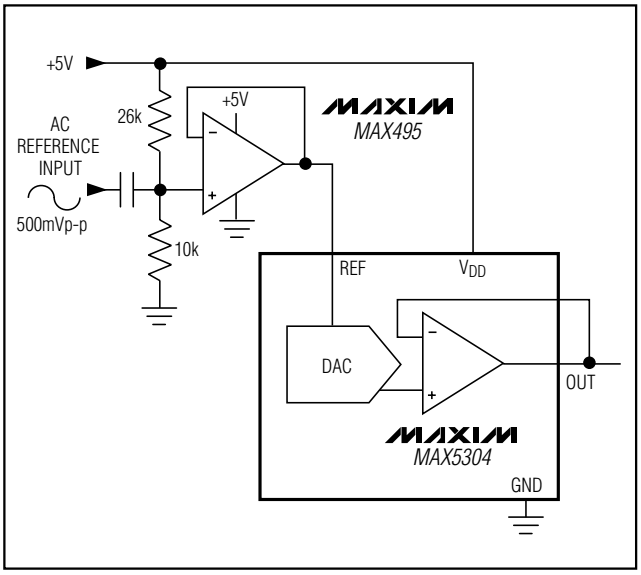


Figure 11. AC Reference Input Circuit

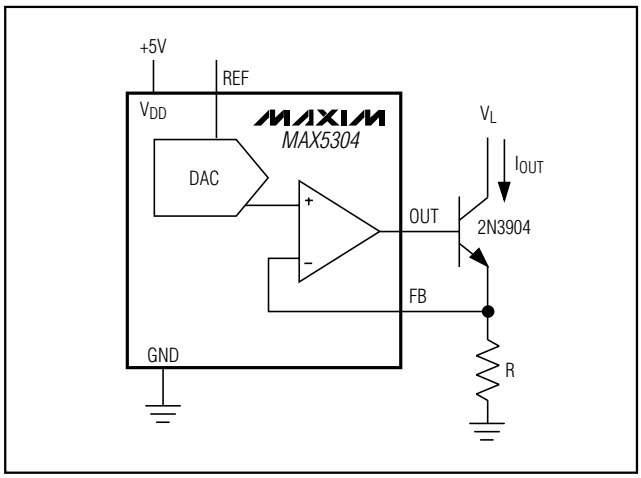


Figure 12. Digitally Programmable Current Source

Power-Supply Considerations

On power-up, the input and DAC registers are cleared (set to zero code). For rated MAX5304 performance, REF must be at least 1.4V below V_{DD}. Bypass V_{DD} with a 4.7µF capacitor in parallel with a 0.1µF 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.

Chip Information

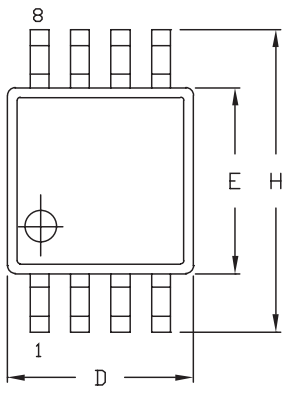
TRANSISTOR COUNT: 3053

SUBSTRATE CONNECTED TO AGND

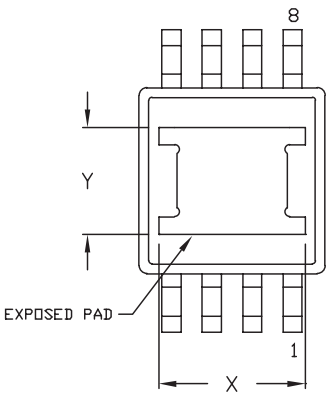
10-Bit Voltage-Output DAC in 8-Pin µMAX

Package Information

8LUMAXD.EPS



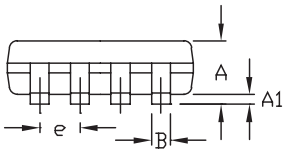
TOP VIEW



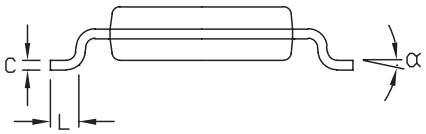
BOTTOM VIEW

	INCHES		MILLIMETERS		JEDEC INCHES		JEDEC MILLIMETERS	
	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



FRONT VIEW



SIDE VIEW

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".

MAXIM

PROPRIETARY INFORMATION

TITLE:

PACKAGE OUTLINE, 8L uMAX

APPROVAL	DOCUMENT CONTROL NO.	REV	
	21-0036	G	1/1