



## TABLE OF CONTENTS

|  |    |   |    |
|--|----|---|----|
| Features .....                                   | 1  | Circuit Operation .....                       | 15 |
| Applications.....                                | 1  | Single-Supply Applications .....              | 16 |
| General Description .....                        | 1  | Adding Gain.....                              | 17 |
| Functional Block Diagram .....                   | 1  | Divider or Programmable Gain Element.....     | 17 |
| Revision History .....                           | 2  | Reference Selection .....                     | 18 |
| Specifications.....                              | 3  | Amplifier Selection .....                     | 18 |
| Timing Characteristics .....                     | 5  | Serial Interface.....                         | 20 |
| Absolute Maximum Ratings.....                    | 7  | Microprocessor Interfacing.....               | 22 |
| ESD Caution.....                                 | 7  | PCB Layout and Power Supply Decoupling .....  | 24 |
| Pin Configuration and Function Descriptions..... | 8  | Overview of the AD5424 to AD5547 Devices..... | 25 |
| Typical Performance Characteristics .....        | 9  | Outline Dimensions .....                      | 26 |
| Terminology .....                                | 14 | Ordering Guide .....                          | 26 |
| General Description .....                        | 15 |   |    |
| DAC Section.....                                 | 15 |   |    |

## REVISION HISTORY

### 12/15—Rev. E to Rev. F

|  |    |
|--|----|
| Deleted Positive Output Voltage Section.....   | 17 |
| Changes to Adding Gain Section .....   | 17 |
| Changes to Reference Selection Section.....  | 18 |
| Changes to ADSP21xx to AD5415 Interface Section,<br>ADSP-BF504 to ADSP-BF592 Device Family to AD5415 Interface<br>Section, Figure 41, and Figure 42..... | 22 |
| Changes to MC68HC11 to AD5415 Interface Section and<br>PIC16C6x/PIC16C7x to AD5415 Interface Section .....   | 23 |
| Changes to Overview of the AD5424 to AD5547 Devices<br>Section Title.....  | 25 |

### 5/13—Rev. D to Rev. E

|                                      |    |
|--------------------------------------|----|
| Changes to General Description ..... | 1  |
| Change to Ordering Guide.....        | 26 |

### 5/12—Rev. C to Rev. D

|   |    |
|---|----|
| Changes SDO Control (SDO1 and SDO2) Section ..... | 20 |
|---|----|

### 6/11—Rev. B to Rev. C

|   |    |
|---|----|
| Changes to General Description .....  | 1  |
| Deleted Evaluation Board for the DAC Section and Power<br>Supplies for the Evaluation Board Section ..... | 24 |
| Changes to Ordering Guide .....   | 26 |

### 4/10—Rev. A to Rev. B

|                     |   |
|---------------------|---|
| Added Figure 4..... | 6 |
|---------------------|---|

### 7/05—Rev. 0 to Rev. A

|   |    |
|---|----|
| Changes to Features List.....                                   | 1  |
| Change to General Description .....                             | 1  |
| Changes to Specifications.....                                  | 3  |
| Changes to Timing Characteristics.....                          | 5  |
| Change to Figure 8 and Figure 9 .....                           | 9  |
| Change to Figure 13 .....                                       | 10 |
| Change to Figure 27 Through Figure 29 .....                     | 12 |
| Change to Figure 32 .....                                       | 15 |
| Changes to Table 5 and Table 6 .....                            | 15 |
| Change to Stability Section .....                               | 16 |
| Changes to Voltage-Switching Mode of Operation Section .....    | 16 |
| Change to Figure 35 .....                                       | 16 |
| Changes to Divider or Programmable Gain Element Section .....   | 17 |
| Changes to Figure 36 Through Figure 38.....                     | 17 |
| Changes to Table 7 Through Table 10 .....                       | 19 |
| Added ADSP-BF5xx-to-AD5415 Interface Section.....               | 22 |
| Change to 80C51/80L51-to-AD5415 Interface Section.....          | 23 |
| Change to MC68HC11-to-AD5415 Interface Section .....            | 23 |
| Change to Power Supplies for the Evaluation Board Section ..... | 24 |
| Changes to Table 13 .....                                       | 28 |
| Updated Outline Dimensions.....                                 | 29 |
| Changes to Ordering Guide .....                                 | 29 |

### 7/04—Revision 0: Initial Version

## SPECIFICATIONS

$V_{DD} = 2.5\text{ V to }5.5\text{ V}$ ,  $V_{REF} = 10\text{ V}$ ,  $I_{OUT2} = 0\text{ V}$ . Temperature range for Y version:  $-40^{\circ}\text{C to }+125^{\circ}\text{C}$ . All specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted. DC performance is measured with [OP177](#), and ac performance is measured with [AD8038](#), unless otherwise noted.

Table 1.<sup>1</sup>

| Parameter  | Min            | Typ      | Max      | Unit                        | Test Conditions/Comments  |  |
|--|----------------|----------|----------|-----------------------------|---|--|
| <b>STATIC PERFORMANCE</b>                          |                |          |          |                             |   |  |
| Resolution   |                |          | 12       | Bits                        | Guaranteed monotonic  |  |
| Relative Accuracy                                  |                |          | $\pm 1$  | LSB                         |   |  |
| Differential Nonlinearity                          |                |          | $-1/+2$  | LSB                         |   |  |
| Gain Error   |                |          | $\pm 25$ | mV                          |   |  |
| Gain Error Temperature Coefficient                 |                | $\pm 5$  |          | ppm FSR/ $^{\circ}\text{C}$ |   |  |
| Bipolar Zero Code Error                            |                |          | $\pm 25$ | mV                          |   |  |
| Output Leakage Current                             |                |          | $\pm 1$  | nA                          |   | Data = 0x0000, $T_A = 25^{\circ}\text{C}$ , $I_{OUT1}$   |
|  |                |          | $\pm 15$ | nA                          | Data = 0x0000, $T_A = -40^{\circ}\text{C to }+125^{\circ}\text{C}$ , $I_{OUT1}$   |  |
| <b>REFERENCE INPUT</b>                             |                |          |          |                             |   |  |
| Reference Input Range                              |                | $\pm 10$ |          | V                           | Input resistance temperature coefficient (TC) = $-50\text{ ppm}/^{\circ}\text{C}$<br>Typ = $25^{\circ}\text{C}$ , max = $125^{\circ}\text{C}$   |  |
| $V_{REFA}$ , $V_{REFB}$ Input Resistance           | 8              | 10       | 13       | k $\Omega$                  |   |  |
| $V_{REFA}$ to $V_{REFB}$ Input Resistance Mismatch |                | 1.6      | 2.5      | %                           |   |  |
| R1, $R_{FB}$ Resistance                            | 17             | 20       | 25       | k $\Omega$                  |   | Input resistance TC = $-50\text{ ppm}/^{\circ}\text{C}$  |
| R2, R3 Resistance                                  | 17             | 20       | 25       | k $\Omega$                  |   | Input resistance TC = $-50\text{ ppm}/^{\circ}\text{C}$  |
| R2 to R3 Resistance Mismatch                       |                | 0.06     | 0.18     | %                           |   | Typ = $25^{\circ}\text{C}$ , max = $125^{\circ}\text{C}$ |
| Input Capacitance                                  |                |          |          |                             |   |  |
| Code 0   |                | 3.5      |          | pF                          |   |  |
| Code 4095  |                | 3.5      |          | pF                          |   |  |
| <b>DIGITAL INPUTS/OUTPUT</b>                       |                |          |          |                             |   |  |
| Input High Voltage, $V_{IH}$                       | 1.7            |          |          | V                           | $V_{DD} = 3.6\text{ V to }5.5\text{ V}$   |  |
|  | 1.7            |          |          | V                           | $V_{DD} = 2.5\text{ V to }3.6\text{ V}$   |  |
| Input Low Voltage, $V_{IL}$                        |                |          | 0.8      | V                           | $V_{DD} = 2.7\text{ V to }5.5\text{ V}$   |  |
|  |                |          | 0.7      | V                           | $V_{DD} = 2.5\text{ V to }2.7\text{ V}$   |  |
| Output High Voltage, $V_{OH}$                      | $V_{DD} - 1$   |          |          | V                           | $V_{DD} = 4.5\text{ V to }5.5\text{ V}$ , $I_{SOURCE} = 200\text{ }\mu\text{A}$   |  |
|  | $V_{DD} - 0.5$ |          |          | V                           | $V_{DD} = 2.5\text{ V to }3.6\text{ V}$ , $I_{SOURCE} = 200\text{ }\mu\text{A}$   |  |
| Output Low Voltage, $V_{OL}$                       |                |          | 0.4      | V                           | $V_{DD} = 4.5\text{ V to }5.5\text{ V}$ , $I_{SINK} = 200\text{ }\mu\text{A}$   |  |
|  |                |          | 0.4      | V                           | $V_{DD} = 2.5\text{ V to }3.6\text{ V}$ , $I_{SINK} = 200\text{ }\mu\text{A}$   |  |
| Input Leakage Current, $I_{IL}$                    |                |          | 1        | $\mu\text{A}$               |   |  |
| Input Capacitance                                  |                | 4        | 10       | pF                          |   |  |
| <b>DYNAMIC PERFORMANCE</b>                         |                |          |          |                             |   |  |
| Reference Multiplying Bandwidth (BW)               |                | 10       |          | MHz                         | $V_{REF} = \pm 3.5\text{ V p-p}$ , DAC loaded all 1s<br>$R_{LOAD} = 100\text{ }\Omega$ , $C_{LOAD} = 15\text{ pF}$ , $V_{REF} = 10\text{ V}$<br>DAC latch alternately loaded with 0s and 1s |  |
| Output Voltage Settling Time                       |                |          |          |                             |   |  |
| Measured to $\pm 1\text{ mV}$ of Full Scale (FS)   |                | 80       | 120      | ns                          |   |  |
| Measured to $\pm 4\text{ mV}$ of FS                |                | 35       | 70       | ns                          |   |  |
| Measured to $\pm 16\text{ mV}$ of FS               |                | 30       | 60       | ns                          |   |  |
| Digital Delay                                      |                | 20       | 40       | ns                          |   |  |
| 10% to 90% Settling Time                           |                | 15       | 30       | ns                          |   |  |
| Digital-to-Analog Glitch Impulse                   |                | 3        |          | nV-sec                      |   |  |
| Multiplying Feedthrough Error                      |                |          | 70       | dB                          |   |  |
|  |                |          | 48       | dB                          |   |  |
| Output Capacitance                                 |                | 12       | 17       | pF                          | Rise and fall times<br>1 LSB change around major carry, $V_{REF} = 0\text{ V}$<br>DAC latches loaded with all 0s, $V_{REF} = \pm 3.5\text{ V}$  |  |
|  |                | 25       | 30       | pF                          | 1 MHz<br>10 MHz<br>DAC latches loaded with all 0s<br>DAC latches loaded with all 1s   |  |

| Parameter                                       | Min | Typ | Max   | Unit                   | Test Conditions/Comments   |
|---|-----|-----|-------|------------------------|--|
| Digital Feedthrough                             |     | 3   | 5     | nV-sec                 | Feedthrough to DAC output with $\overline{CS}$ high and alternate loading of all 0s and all 1s |
| Output Noise Spectral Density                   |     | 25  |       | nV/ $\sqrt{\text{Hz}}$ | At 1 kHz   |
| Analog THD                                      |     | 81  |       | dB                     | $V_{REF} = 3.5 \text{ V p-p}$ , all 1s loaded, $f = 1 \text{ kHz}$                             |
| Digital THD                                     |     |     |       |                        | Clock = 10 MHz, $V_{REF} = 3.5 \text{ V}$  |
| 100 kHz $f_{OUT}$                               |     | 61  |       | dB                     |  |
| 50 kHz $f_{OUT}$                                |     | 66  |       | dB                     |  |
| SFDR Performance (Wide Band)                    |     |     |       |                        | $V_{REF} = 3.5 \text{ V}$  |
| Clock = 10 MHz                                  |     |     |       |                        |  |
| 500 kHz $f_{OUT}$                               |     | 55  |       | dB                     |  |
| 100 kHz $f_{OUT}$                               |     | 63  |       | dB                     |  |
| 50 kHz $f_{OUT}$                                |     | 65  |       | dB                     |  |
| Clock = 25 MHz                                  |     |     |       |                        |  |
| 500 kHz $f_{OUT}$                               |     | 50  |       | dB                     |  |
| 100 kHz $f_{OUT}$                               |     | 60  |       | dB                     |  |
| 50 kHz $f_{OUT}$                                |     | 62  |       | dB                     |  |
| SFDR Performance (Narrow Band)                  |     |     |       |                        | $V_{REF} = 3.5 \text{ V}$  |
| Clock = 10 MHz                                  |     |     |       |                        |  |
| 500 kHz $f_{OUT}$                               |     | 73  |       | dB                     |  |
| 100 kHz $f_{OUT}$                               |     | 80  |       | dB                     |  |
| 50 kHz $f_{OUT}$                                |     | 87  |       | dB                     |  |
| Clock = 25 MHz                                  |     |     |       |                        |  |
| 500 kHz $f_{OUT}$                               |     | 70  |       | dB                     |  |
| 100 kHz $f_{OUT}$                               |     | 75  |       | dB                     |  |
| 50 kHz $f_{OUT}$                                |     | 80  |       | dB                     |  |
| Intermodulation Distortion                      |     |     |       |                        | $V_{REF} = 3.5 \text{ V}$  |
| $f_1 = 40 \text{ kHz}$ , $f_2 = 50 \text{ kHz}$ |     | 72  |       | dB                     | Clock = 10 MHz   |
| $f_1 = 40 \text{ kHz}$ , $f_2 = 50 \text{ kHz}$ |     | 65  |       | dB                     | Clock = 25 MHz   |
| <b>POWER REQUIREMENTS</b>                       |     |     |       |                        |  |
| Power Supply Range                              | 2.5 |     | 5.5   | V                      |  |
| $I_{DD}$  |     |     | 0.7   | $\mu\text{A}$          | $T_A = 25^\circ\text{C}$ , logic inputs = 0 V or $V_{DD}$                                      |
|   |     | 0.5 | 10    | $\mu\text{A}$          | $T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ , logic inputs = 0 V or $V_{DD}$             |
| Power Supply Sensitivity                        |     |     | 0.001 | %/%                    | $\Delta V_{DD} = \pm 5\%$  |

<sup>1</sup> Guaranteed by design and characterization, not subject to production test.

**TIMING CHARACTERISTICS**

All input signals are specified with  $t_r = t_f = 1 \text{ ns}$  (10% to 90% of  $V_{DD}$ ) and timed from a voltage level of  $(V_{IL} + V_{IH})/2$ .  $V_{DD} = 2.5 \text{ V}$  to  $5.5 \text{ V}$ ,  $V_{REF} = 10 \text{ V}$ ,  $I_{OUT2} = 0 \text{ V}$ , temperature range for Y version:  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$ . All specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

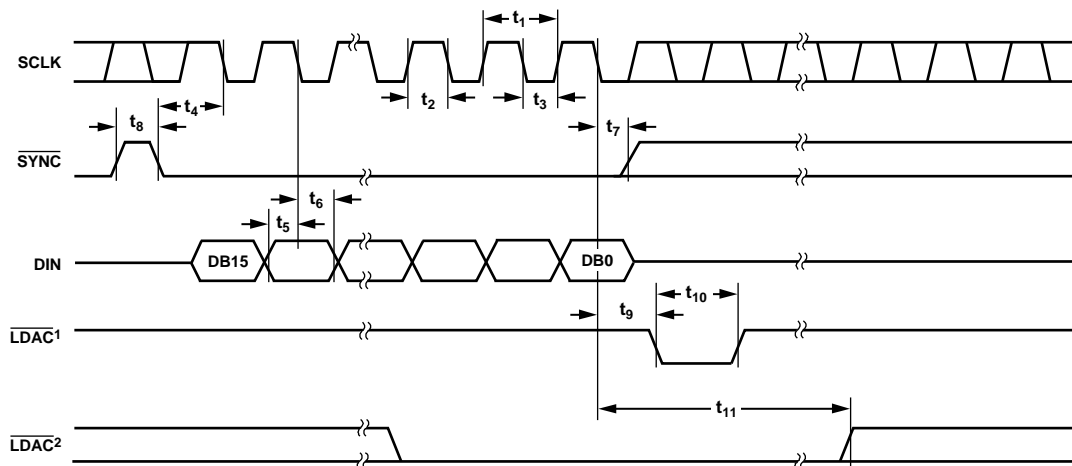
**Table 2.**

| Parameter <sup>1</sup> | Limit at $T_{MIN}$ , $T_{MAX}$ | Unit    | Test Conditions/Comments <sup>2</sup>   |
|------------------------|--------------------------------|---------|---|
| $f_{SCLK}$             | 50                             | MHz max | Maximum clock frequency   |
| $t_1$                  | 20                             | ns min  | SCLK cycle time   |
| $t_2$                  | 8                              | ns min  | SCLK high time  |
| $t_3$                  | 8                              | ns min  | SCLK low time   |
| $t_4$                  | 13                             | ns min  | $\overline{SYNC}$ falling edge to SCLK falling edge setup time                                    |
| $t_5$                  | 5                              | ns min  | Data setup time   |
| $t_6$                  | 4                              | ns min  | Data hold time  |
| $t_7$                  | 5                              | ns min  | $\overline{SYNC}$ rising edge to SCLK falling edge  |
| $t_8$                  | 30                             | ns min  | Minimum $\overline{SYNC}$ high time   |
| $t_9$                  | 0                              | ns min  | SCLK falling edge to $\overline{LDAC}$ falling edge   |
| $t_{10}$               | 12                             | ns min  | $\overline{LDAC}$ pulse width   |
| $t_{11}$               | 10                             | ns min  | SCLK falling edge to $\overline{LDAC}$ rising edge  |
| $t_{12}^3$             | 25                             | ns min  | SCLK active edge to SDO valid, strong SDO driver  |
|                        | 60                             | ns min  | SCLK active edge to SDO valid, weak SDO driver  |
| Update Rate            | 2.47                           | MSPS    | Consists of cycle time, $\overline{SYNC}$ high time, data setup, and output voltage settling time |

<sup>1</sup> Guaranteed by design and characterization, not subject to production test.

<sup>2</sup> Falling or rising edge as determined by the control bits of the serial word. Strong or weak SDO driver selected via the control register.

<sup>3</sup> Daisy-chain and readback modes cannot operate at maximum clock frequency. SDO timing specifications measured with a load circuit, as shown in Figure 5.

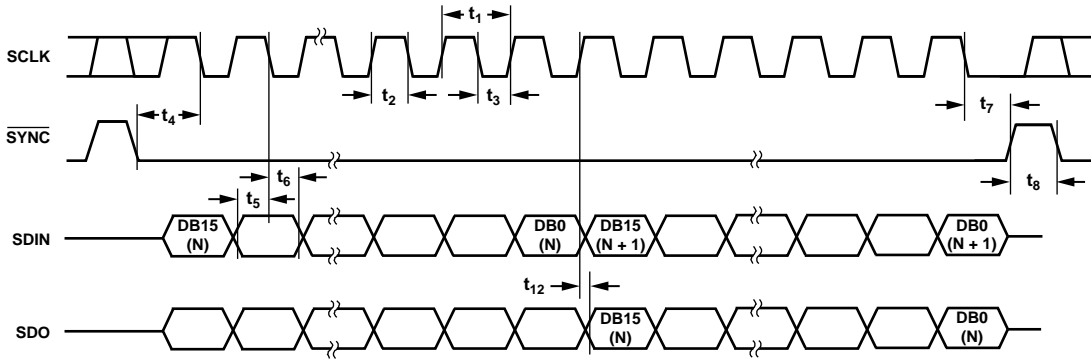


<sup>1</sup>ASYNCHRONOUS LDAC UPDATE MODE.  
<sup>2</sup>SYNCHRONOUS LDAC UPDATE MODE.

NOTES  
 ALTERNATIVELY, DATA CAN BE CLOCKED INTO THE INPUT SHIFT REGISTER ON THE RISING EDGE OF SCLK AS DETERMINED BY THE CONTROL BITS. TIMING IS AS ABOVE, WITH SCLK INVERTED.

04461-002

Figure 2. Standalone Mode Timing Diagram

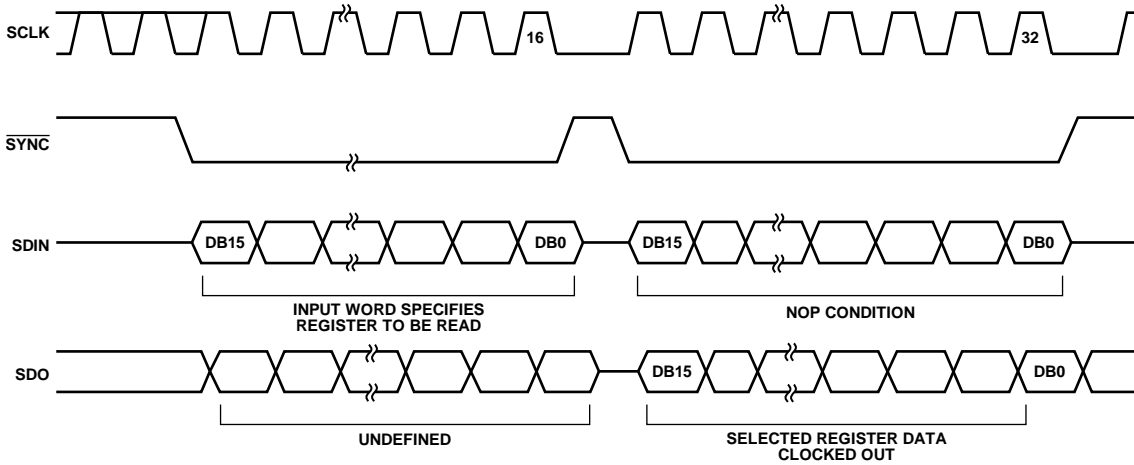


NOTES

1. ALTERNATIVELY, DATA CAN BE CLOCKED INTO THE INPUT SHIFT REGISTER ON THE RISING EDGE OF SCLK AS DETERMINED BY THE CONTROL BITS. IN THIS CASE, DATA IS CLOCKED OUT OF SDO ON THE FALLING EDGE OF SCLK. TIMING IS AS ABOVE, WITH SCLK INVERTED.

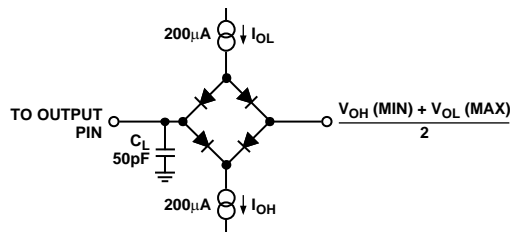
04481-003

Figure 3. Daisy-Chain Timing Diagram



04481-003

Figure 4. Readback Mode Timing Diagram



04481-004

Figure 5. Load Circuit for SDO Timing Specifications

## ABSOLUTE MAXIMUM RATINGS

Transient currents of up to 100 mA do not cause SCR latch-up.  
 $T_A = 25^\circ\text{C}$ , unless otherwise noted.

Table 3.

| Parameter  | Rating                     |
|--|----------------------------|
| $V_{DD}$ to GND                                  | -0.3 V to +7 V             |
| $V_{REF}$ , $R_{FB}$ to GND                      | -12 V to +12 V             |
| $I_{OUT1}$ , $I_{OUT2}$ to GND                   | -0.3 V to +7 V             |
| Input Current to Any Pin Except Supplies         | $\pm 10$ mA                |
| Logic Inputs and Output <sup>1</sup>             | -0.3 V to $V_{DD} + 0.3$ V |
| Operating Temperature Range                      |                            |
| Extended (Y Version)                             | -40°C to +125°C            |
| Storage Temperature Range                        | -65°C to +150°C            |
| Junction Temperature                             | 150°C                      |
| 24-Lead TSSOP, $\theta_{JA}$ Thermal Impedance   | 128°C/W                    |
| Lead Temperature, Soldering (10 sec)             | 300°C                      |
| Infrared (IR) Reflow, Peak Temperature (<20 sec) | 235°C                      |

<sup>1</sup> Overvoltages at SCLK,  $\overline{\text{SYNC}}$ , and SDIN are clamped by internal diodes.

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

### 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

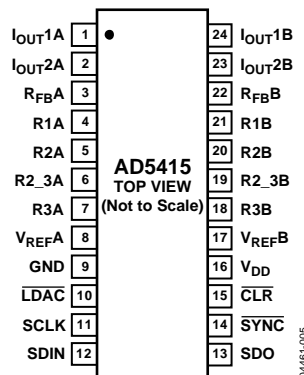


Figure 6. Pin Configuration

Table 4. Pin Function Descriptions

| Pin No.  | Mnemonic             | Description  |
|----------|----------------------|--|
| 1        | I <sub>OUT1A</sub>   | DAC A Current Output.  |
| 2        | I <sub>OUT2A</sub>   | DAC A Analog Ground. This pin is normally tied to the analog ground of the system, but can be biased to achieve single-supply operation.   |
| 3        | R <sub>FB A</sub>    | DAC Feedback Resistor Pin. This pin establishes voltage output for the DAC by connecting to an external amplifier output.  |
| 4 to 7   | R1A, R2A, R2_3A, R3A | DAC A 4-Quadrant Resistors. These pins allow a number of configuration modes, including bipolar operation, with minimum external components.   |
| 8        | V <sub>REF A</sub>   | DAC A Reference Voltage Input Pin.   |
| 9        | GND                  | Ground Pin.  |
| 10       | LDAC                 | Load DAC Input. This pin allows asynchronous or synchronous updates to the DAC output. The DAC is asynchronously updated when this signal goes low. Alternatively, if this line is held permanently low, an automatic or synchronous update mode is selected, whereby the DAC is updated on the 16th clock falling edge when the device is in standalone mode, or on the rising edge of SYNC when in daisy-chain mode.   |
| 11       | SCLK                 | Serial Clock Input. By default, data is clocked into the input shift register on the falling edge of the serial clock input. Alternatively, by means of the serial control bits, the device can be configured such that data is clocked into the shift register on the rising edge of SCLK.  |
| 12       | SDIN                 | Serial Data Input. Data is clocked into the 16-bit input register on the active edge of the serial clock input. By default, on power-up data is clocked into the shift register on the falling edge of SCLK. The control bits allow the user to change the active edge to the rising edge.   |
| 13       | SDO                  | Serial Data Output. This pin allows a number of devices to be daisy-chained. By default, data is clocked into the shift register on the falling edge and clocked out via SDO on the rising edge of SCLK. Data is always clocked out on the alternate edge to loading data to the shift register. Writing the readback control word to the shift register makes the DAC register contents available for readback on the SDO pin; they are clocked out on the next 16 opposite clock edges to the active clock edge. |
| 14       | SYNC                 | Active Low Control Input. This pin provides the frame synchronization signal for the input data. When SYNC goes low, it powers on the SCLK and SDIN buffers, and the input shift register is enabled. Data is loaded into the shift register on the active edge of the subsequent clocks. In standalone mode, the serial interface counts the clocks, and data is latched into the shift register on the 16th active clock edge.   |
| 15       | CLR                  | Active Low Control Input. This pin clears the DAC output, input, and DAC registers. Configuration mode allows the user to enable the hardware CLR pin as a clear to zero scale or midscale as required.  |
| 16       | V <sub>DD</sub>      | Positive Power Supply Input. This device can be operated from a supply of 2.5 V to 5.5 V.  |
| 17       | V <sub>REF B</sub>   | DAC B Reference Voltage Input Pin.   |
| 18 to 21 | R3B, R2_3B, R2B, R1B | DAC B 4-Quadrant Resistors. These pins allow a number of configuration modes, including bipolar operation, with a minimum of external components.  |
| 22       | R <sub>FB B</sub>    | DAC B Feedback Resistor Pin. This pin establishes voltage output for the DAC by connecting to the external amplifier output.   |
| 23       | I <sub>OUT2B</sub>   | DAC B Analog Ground. This pin is normally tied to the analog ground of the system, but can be biased to achieve single-supply operation.   |
| 24       | I <sub>OUT1B</sub>   | DAC B Current Output.  |



TYPICAL PERFORMANCE CHARACTERISTICS

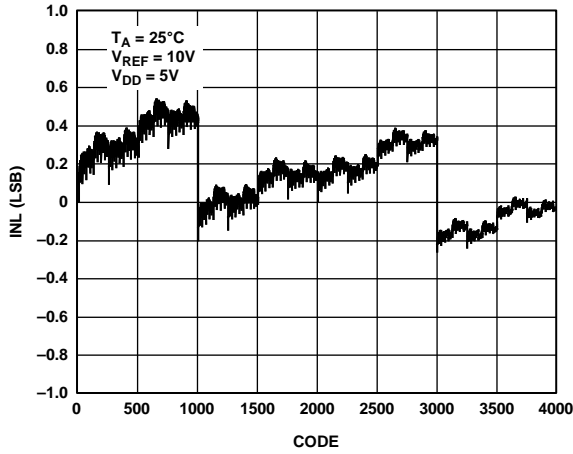


Figure 7. Integral Nonlinearity (INL) vs. Code (12-Bit DAC)

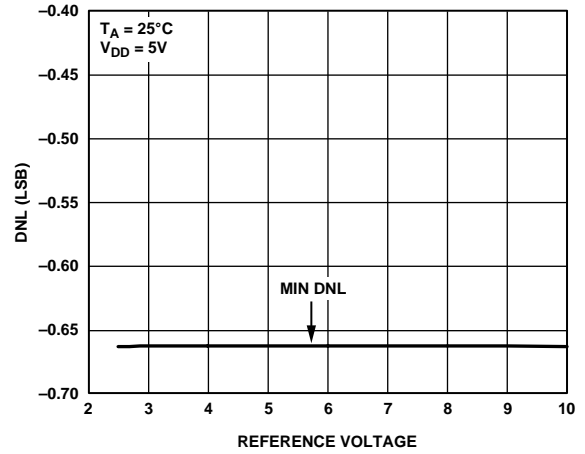


Figure 10. DNL vs. Reference Voltage

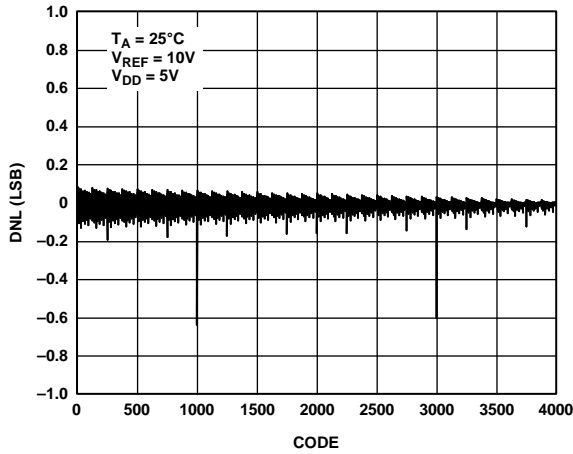


Figure 8. Differential Nonlinearity (DNL) vs. Code (12-Bit DAC)

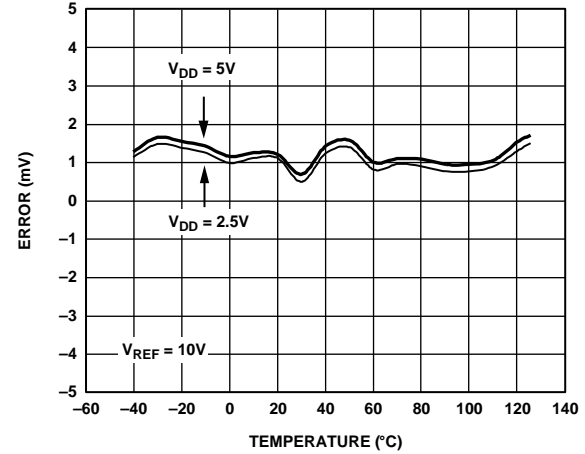


Figure 11. Gain Error vs. Temperature

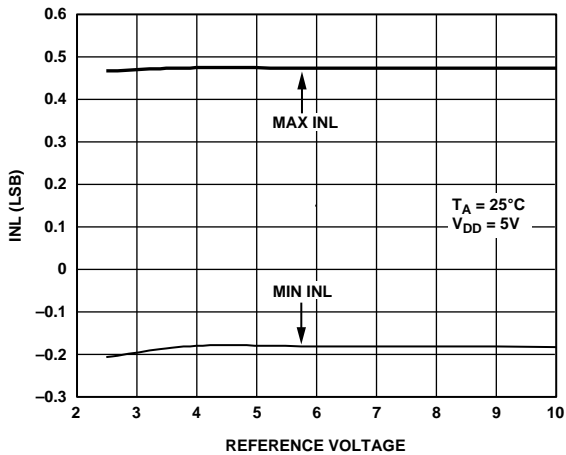


Figure 9. INL vs. Reference Voltage

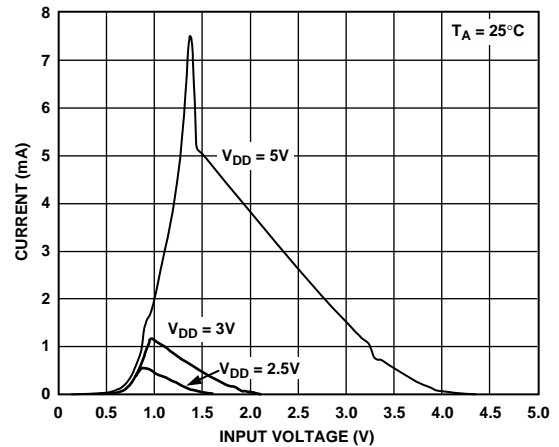


Figure 12. Supply Current vs. Logic Input Voltage

04461-006

04461-009

04461-007

04461-010

04461-008

04461-011

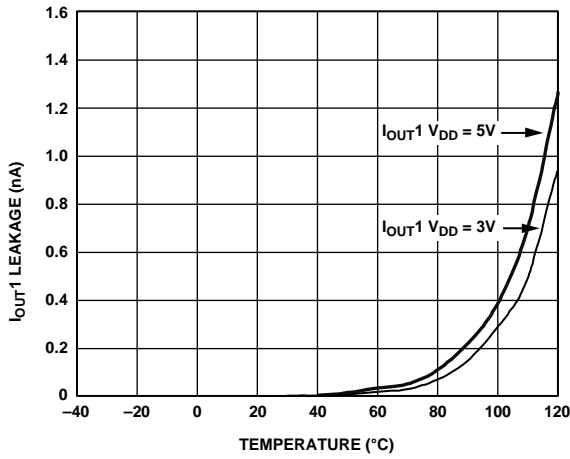


Figure 13.  $I_{out1}$  Leakage Current vs. Temperature

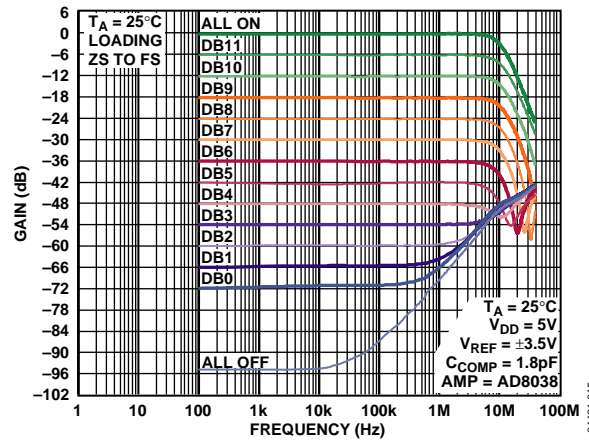


Figure 16. Reference Multiplying Bandwidth vs. Frequency and Code

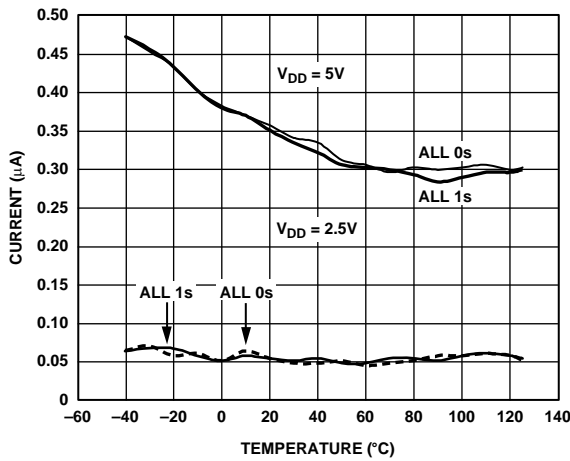


Figure 14. Supply Current vs. Temperature

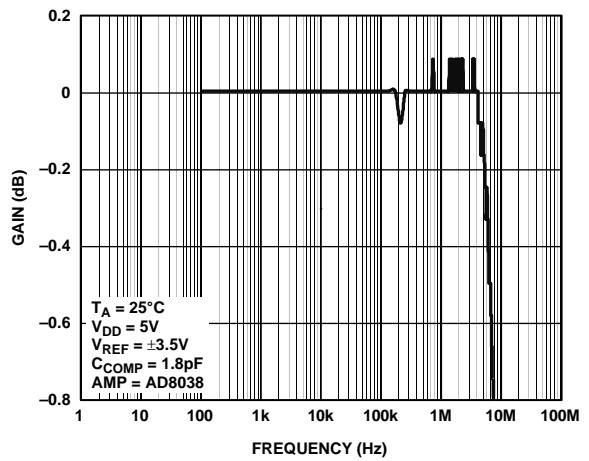


Figure 17. Reference Multiplying Bandwidth—All 1s Loaded

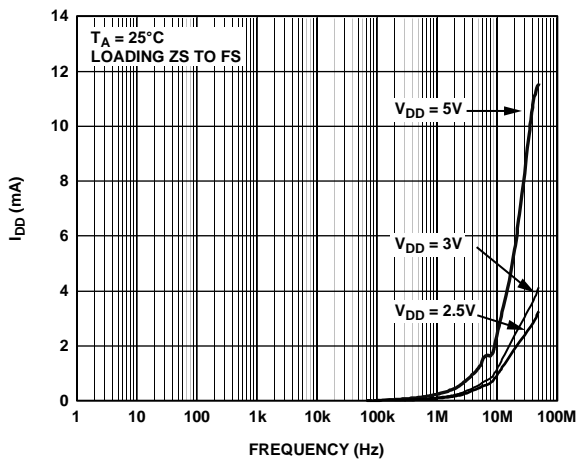


Figure 15. Supply Current vs. Update Rate

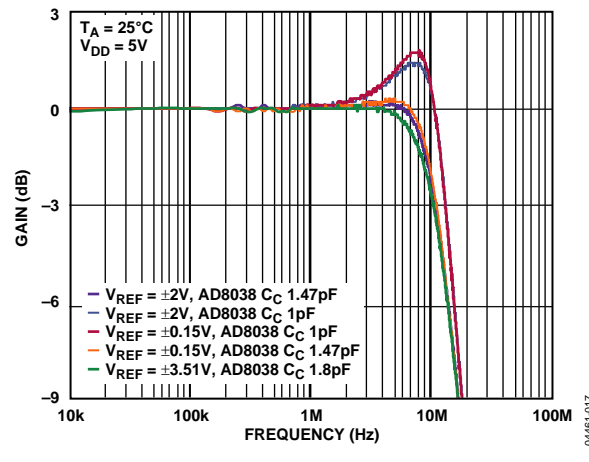


Figure 18. Reference Multiplying Bandwidth vs. Frequency and Compensation Capacitor

04461-012

04461-015

04461-013

04461-016

04461-014

04461-017

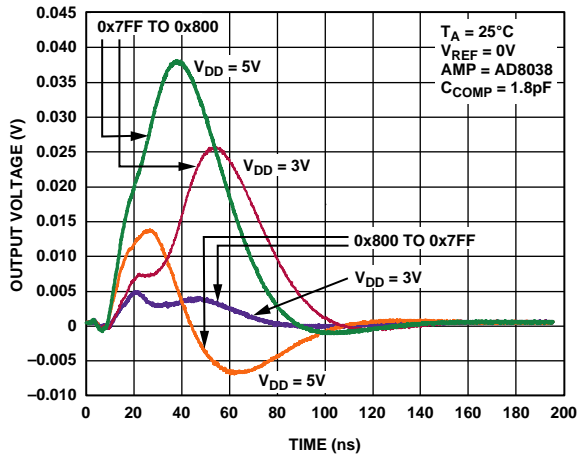


Figure 19. Midscale Transition,  $V_{REF} = 0V$

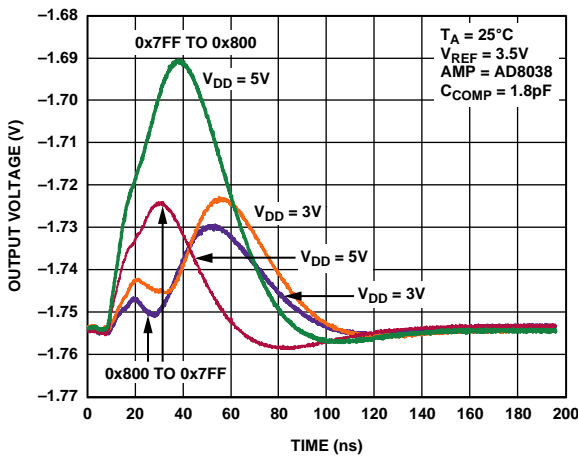


Figure 20. Midscale Transition,  $V_{REF} = 3.5V$

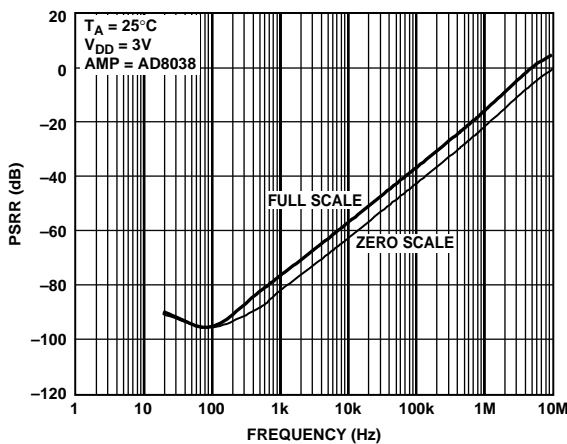


Figure 21. Power Supply Rejection Ratio vs. Frequency

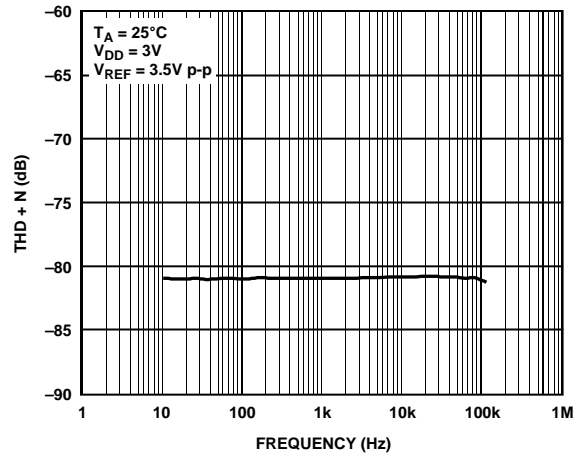


Figure 22. THD and Noise vs. Frequency

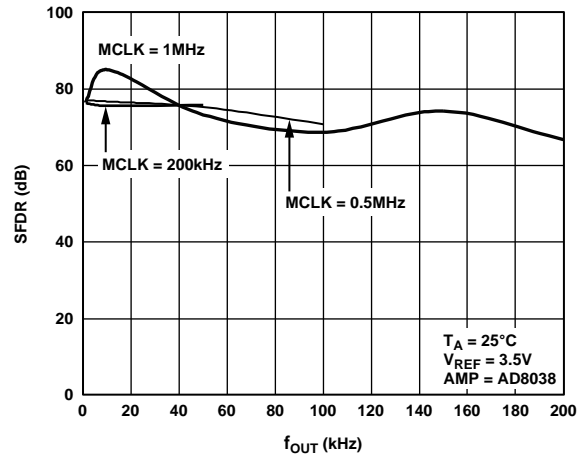


Figure 23. Wideband Spurious-Free Dynamic Range (SFDR) vs.  $f_{OUT}$  Frequency

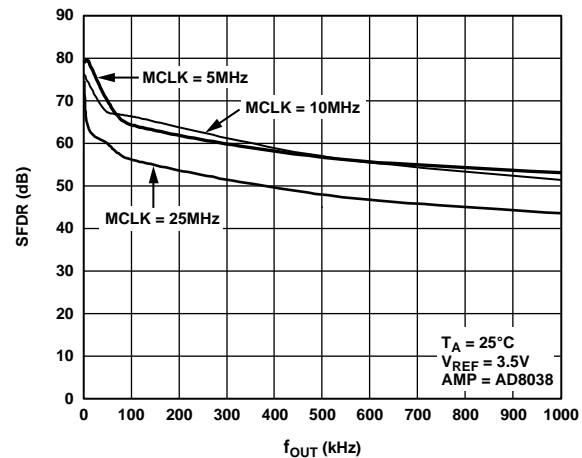


Figure 24. Wideband SFDR vs.  $f_{OUT}$  Frequency

04461-018

04461-021

04461-019

04461-022

04461-020

04461-023

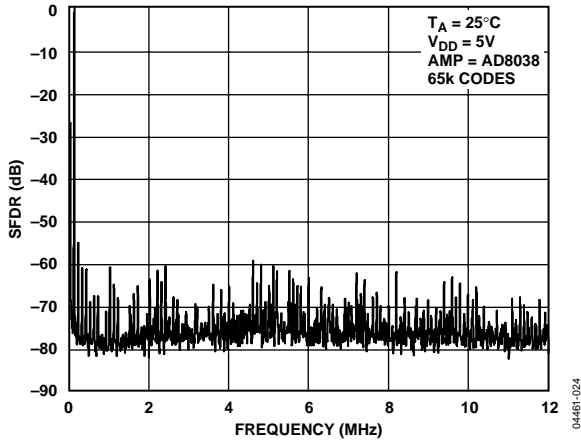


Figure 25. Wideband SFDR,  $f_{OUT} = 100$  kHz, Clock = 25 MHz

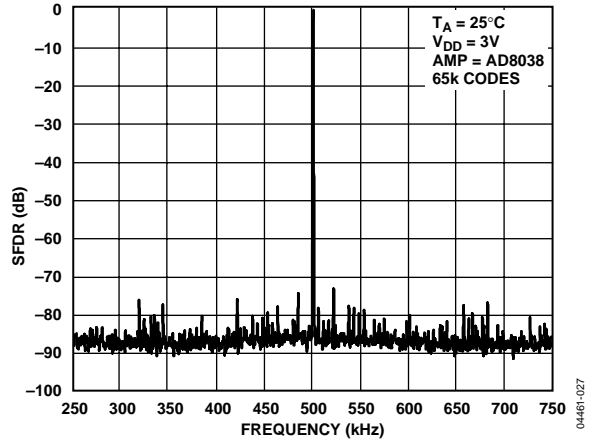


Figure 28. Narrow-Band Spectral Response,  $f_{OUT} = 500$  kHz, Clock = 25 MHz

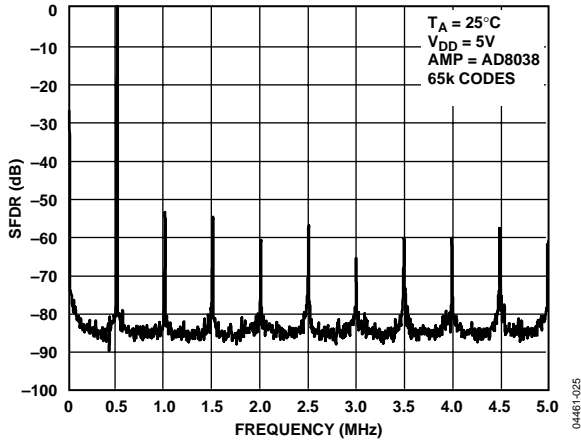


Figure 26. Wideband SFDR,  $f_{OUT} = 500$  kHz, Clock = 10 MHz

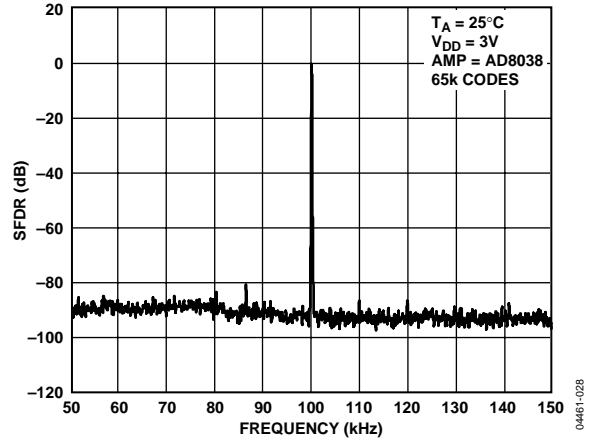


Figure 29. Narrow-Band SFDR,  $f_{OUT} = 100$  kHz, MCLK = 25 MHz

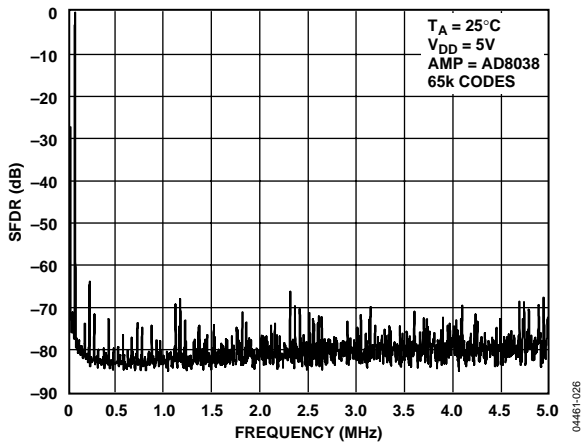


Figure 27. Wideband SFDR,  $f_{OUT} = 50$  kHz, Clock = 10 MHz

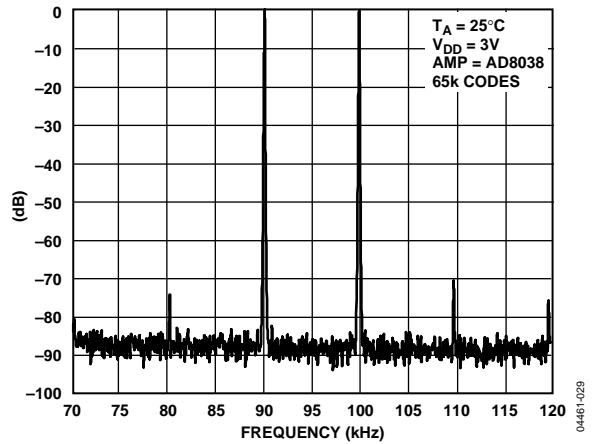


Figure 30. Narrow-Band Intermodulation Distortion (IMD),  $f_{OUT} = 90$  kHz, 100 kHz, Clock = 10 MHz

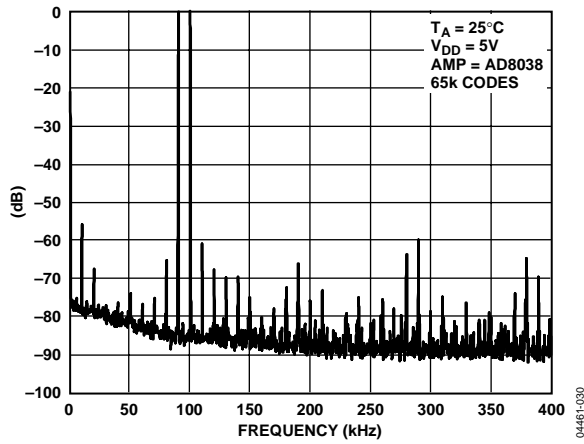


Figure 31. Wideband IMD,  $f_{OUT} = 90\text{ kHz}$ ,  $100\text{ kHz}$ , Clock = 25 MHz

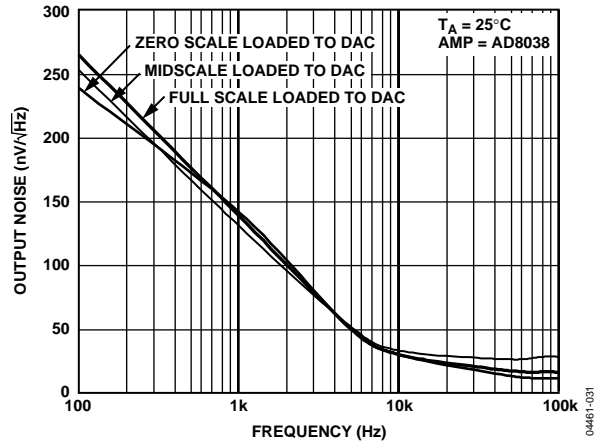


Figure 32. Output Noise Spectral Density

## TERMINOLOGY

### Relative Accuracy (Endpoint Nonlinearity)

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 and full scale and is normally expressed in LSB or as a percentage of the full-scale reading.

### Differential Nonlinearity

The difference in the measured change and the ideal 1 LSB change between two adjacent codes. A specified differential nonlinearity of  $-1$  LSB maximum over the operating temperature range ensures monotonicity.

### Gain Error (Full-Scale Error)

A measure of the output error between an ideal DAC and the actual device output. For this DAC, ideal maximum output is  $V_{REF} - 1$  LSB. The gain error of the DAC is adjustable to zero with an external resistance.

### Output Leakage Current

The current that flows into the DAC ladder switches when they are turned off. For the  $I_{OUT1}$  terminal, it can be measured by loading all 0s to the DAC and measuring the  $I_{OUT1}$  current. Minimum current flows into the  $I_{OUT2}$  line when the DAC is loaded with all 1s.

### Output Capacitance

Capacitance from  $I_{OUT1}$  or  $I_{OUT2}$  to AGND.

### Output Current Settling Time

The amount of time for the output to settle to a specified level for a full-scale input change. For this device, it is specified with a  $100\ \Omega$  resistor to ground.

### Digital-to-Analog Glitch Impulse

The amount of charge injected from the digital inputs to the analog output when the inputs change state. This is normally specified as the area of the glitch in either pA-sec or nV-sec, depending on whether the glitch is measured as a current or voltage signal.

### Digital Feedthrough

When the device is not selected, high frequency logic activity on the digital inputs of the device is capacitively coupled through the device and produces noise on the  $I_{OUT}$  pins and, subsequently, on the following circuitry. This noise is digital feedthrough.

### Multiplying Feedthrough Error

The error due to capacitive feedthrough from the DAC reference input to the DAC  $I_{OUT1}$  terminal when all 0s are loaded to the DAC.

### Digital Crosstalk

The glitch impulse transferred to the outputs of one DAC in response to a full-scale code change (all 0s to all 1s, or vice versa) in the input register of the other DAC. It is expressed in nV-sec.

### Analog Crosstalk

The glitch impulse transferred to the output of one DAC due to a change in the output of another DAC. It is measured by loading one of the input registers with a full-scale code change (all 0s to all 1s, or vice versa) while keeping  $\overline{LDAC}$  high and then pulsing  $\overline{LDAC}$  low and monitoring the output of the DAC whose digital code has not changed. The area of the glitch is expressed in nV-sec.

### Channel-to-Channel Isolation

The portion of input signal from a DAC reference input that appears at the output of another DAC. It is expressed in decibels.

### Total Harmonic Distortion (THD)

The DAC is driven by an ac reference. The ratio of the rms sum of the harmonics of the DAC output to the fundamental value is the THD. Usually only the lower-order harmonics are included, such as the second to fifth harmonics.

$$THD = 20 \log \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2}}{V_1}$$

### Intermodulation Distortion (IMD)

The DAC is driven by two combined sine wave references of frequencies  $f_a$  and  $f_b$ . Distortion products are produced at sum and difference frequencies of  $m f_a \pm n f_b$ , where  $m, n = 0, 1, 2, 3 \dots$ . Intermodulation terms are those for which  $m$  or  $n$  is not equal to 0. The second-order terms include  $(f_a + f_b)$  and  $(f_a - f_b)$ , and the third-order terms are  $(2f_a + f_b)$ ,  $(2f_a - f_b)$ ,  $(f_a + 2f_b)$ , and  $(f_a - 2f_b)$ . IMD is defined as

$$IMD = 20 \log \frac{\text{(rms sum of the sum and diff distortion products)}}{\text{rms amplitude of the fundamental}}$$

### Compliance Voltage Range

The maximum range of (output) terminal voltage for which the device provides the specified characteristics.

# GENERAL DESCRIPTION

## DAC SECTION

The AD5415 is a 12-bit, dual-channel, current output DAC consisting of standard inverting R-2R ladder configuration. Figure 33 shows a simplified diagram of a single channel of the AD5415. The feedback resistor  $R_{FB}$  has a value of  $2R$ . The value of  $R$  is typically  $10\text{ k}\Omega$  (with a minimum of  $8\text{ k}\Omega$  and a maximum of  $12\text{ k}\Omega$ ). If  $I_{OUT1}$  and  $I_{OUT2}$  are kept at the same potential, a constant current flows into each ladder leg, regardless of the digital input code. Therefore, the input resistance presented at  $V_{REF}$  is always constant.

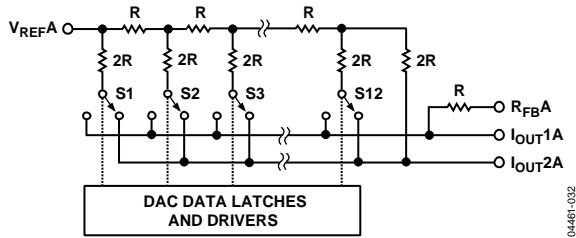


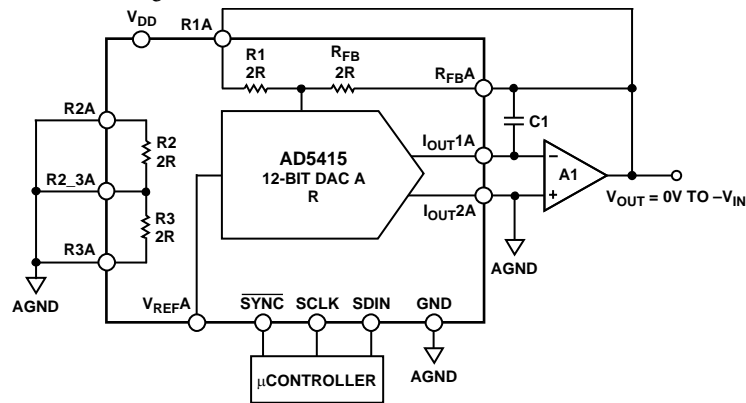
Figure 33. Simplified Ladder

Access is provided to the  $V_{REF}$ ,  $R_{FB}$ ,  $I_{OUT1}$ , and  $I_{OUT2}$  terminals of the DAC, making the device extremely versatile and allowing it to be configured in several operating modes, such as unipolar output, bipolar output, or single-supply mode.

## CIRCUIT OPERATION

### Unipolar Mode

Using a single operational amplifier, this device can easily be configured to provide 2-quadrant multiplying operation or a unipolar output voltage swing, as shown in Figure 34.



- NOTES
1. DAC B OMITTED FOR CLARITY.
  2. C1 PHASE COMPENSATION (1pF TO 2pF) MAY BE REQUIRED IF A1 IS A HIGH SPEED AMPLIFIER.

Figure 34. Unipolar Operation

When an output amplifier is connected in unipolar mode, the output voltage is given by

$$V_{OUT} = -V_{REF} \times D/2^n$$

where:

$D$  is the fractional representation, in the range of 0 to 4,095, of the digital word loaded to the DAC.

$n$  is the number of bits.

Note that the output voltage polarity is opposite the  $V_{REF}$  polarity for dc reference voltages. This DAC is designed to operate with either negative or positive reference voltages. The  $V_{DD}$  power pin is only used by the internal digital logic to drive the on and off states of the DAC switches.

This DAC is also designed to accommodate ac reference input signals in the range of  $-10\text{ V}$  to  $+10\text{ V}$ .

With a fixed  $10\text{ V}$  reference, the circuit in Figure 34 gives a unipolar  $0\text{ V}$  to  $-10\text{ V}$  output voltage swing. When  $V_{IN}$  is an ac signal, the circuit performs 2-quadrant multiplication.

Table 5 shows the relationship between digital code and expected output voltage for unipolar operation.

Table 5. Unipolar Code

| Digital Input  | Analog Output (V)                     |
|----------------|---------------------------------------|
| 1111 1111 1111 | $-V_{REF} (4,095/4,096)$              |
| 1000 0000 0000 | $-V_{REF} (2,048/4,096) = -V_{REF}/2$ |
| 0000 0000 0001 | $-V_{REF} (1/4,096)$                  |
| 0000 0000 0000 | $-V_{REF} (0/4,096) = 0$              |

### Bipolar Operation

In some applications, it may be necessary to generate full 4-quadrant multiplying operation or a bipolar output swing. This can easily be accomplished by using another external amplifier and the on-chip 4-quadrant resistors, as shown in Figure 35.

When in bipolar mode, the output voltage is given by

$$V_{OUT} = (V_{REF} \times D/2^{n-1}) - V_{REF}$$

where:

$D$  is the fractional representation, in the range of 0 to 4,095, of the digital word loaded to the DAC.

$n$  is the number of bits.

When  $V_{IN}$  is an ac signal, the circuit performs 4-quadrant multiplication.

Table 6 shows the relationship between digital code and the expected output voltage for bipolar operation.

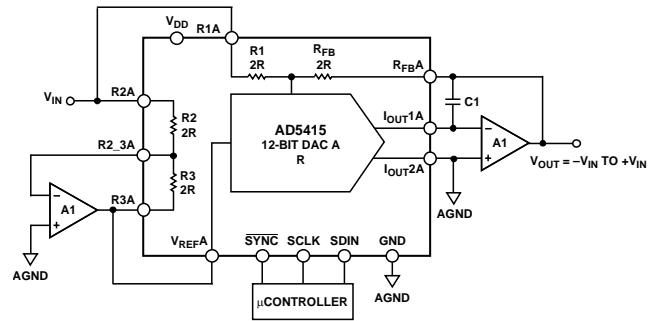
**Table 6. Bipolar Code**

| Digital Input  | Analog Output (V)       |
|----------------|-------------------------|
| 1111 1111 1111 | + $V_{REF}$ (4095/4096) |
| 1000 0000 0000 | 0                       |
| 0000 0000 0001 | - $V_{REF}$ (4095/4096) |
| 0000 0000 0000 | - $V_{REF}$ (4096/4096) |

### Stability

In the I-to-V configuration, the  $I_{OUT}$  of the DAC and the inverting node of the operational amplifier must be connected as close as possible, and proper printed circuit board (PCB) layout techniques must be used. Because every code change corresponds to a step function, gain peaking may occur if the operational amplifier has limited gain bandwidth product (GBP) and there is excessive parasitic capacitance at the inverting node. This parasitic capacitance introduces a pole into the open-loop response, which can cause ringing or instability in the closed-loop applications circuit.

An optional compensation capacitor,  $C1$ , can be added in parallel with  $R_{FBA}$  for stability, as shown in Figure 34 and Figure 35. Too small a value of  $C1$  can produce ringing at the output, whereas too large a value can adversely affect the settling time.  $C1$  must be found empirically, but 1 pF to 2 pF is generally adequate for the compensation.



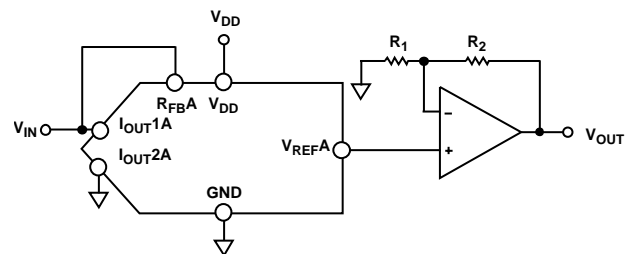
NOTES  
1. DAC B OMITTED FOR CLARITY.  
2.  $C1$  PHASE COMPENSATION (1pF TO 2pF) MAY BE REQUIRED IF A1 IS A HIGH SPEED AMPLIFIER.

Figure 35. Bipolar Operation

## SINGLE-SUPPLY APPLICATIONS

### Voltage Switching Mode of Operation

Figure 36 shows the DAC operating in the voltage switching mode. The reference voltage,  $V_{IN}$ , is applied to the  $I_{OUT1A}$  pin,  $I_{OUT2A}$  is connected to AGND, and the output voltage is available at the  $V_{REFA}$  terminal. In this configuration, a positive reference voltage results in a positive output voltage, making single-supply operation possible. The output from the DAC is voltage at a constant impedance (the DAC ladder resistance). Therefore, an operational amplifier is necessary to buffer the output voltage. The reference input no longer sees a constant input impedance, but one that varies with code. Therefore, the voltage input must be driven from a low impedance source.



NOTES  
1. SIMILAR CONFIGURATION FOR DACB  
2.  $C1$  PHASE COMPENSATION (1pF TO 2pF) MAY BE REQUIRED IF A1 IS A HIGH SPEED AMPLIFIER.

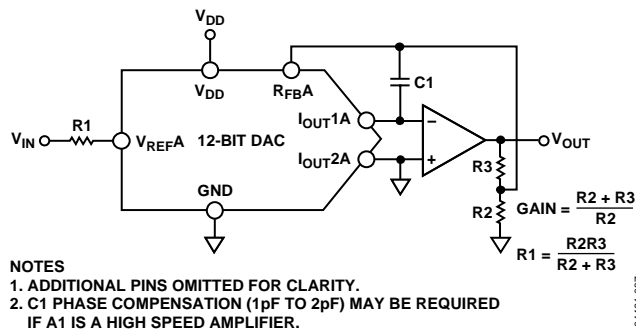
Figure 36. Single-Supply Voltage Switching Mode

Note that  $V_{IN}$  is limited to low voltages because the switches in the DAC ladder no longer have the same source-drain drive voltage. As a result, the on resistance differs and degrades the integral linearity of the DAC. Also,  $V_{IN}$  must not go negative by more than 0.3 V or an internal diode turns on, causing the device to exceed the maximum ratings. In this type of application, the full range of multiplying capability of the DAC is lost.



**ADDING GAIN**

In applications where the output voltage must be greater than  $V_{IN}$ , gain can be added with an additional external amplifier or it can be achieved in a single stage. Consider the effect of temperature coefficients of the thin film resistors of the DAC. Simply placing a resistor in series with the  $R_{FB}$  resistor causes mismatches in the temperature coefficients, resulting in larger gain temperature coefficient errors. Instead, the circuit in Figure 37 shows the recommended method for increasing the gain of the circuit.  $R_1$ ,  $R_2$ , and  $R_3$  can have similar temperature coefficients, but they need not match the temperature coefficients of the DAC. This approach is recommended in circuits where gains greater than 1 are required. Note that  $R_{FB} \gg R_2//R_3$  and a gain error percentage of  $100 \times (R_2//R_3)/R_{FB}$  must be taken into consideration.



- NOTES**  
 1. ADDITIONAL PINS OMITTED FOR CLARITY.  
 2. C1 PHASE COMPENSATION (1pF TO 2pF) MAY BE REQUIRED IF A1 IS A HIGH SPEED AMPLIFIER.

Figure 37. Increasing the Gain of the Current Output DAC

**DIVIDER OR PROGRAMMABLE GAIN ELEMENT**

Current steering DACs are very flexible and lend themselves to many applications. If this type of DAC is connected as the feedback element of an operational amplifier and  $R_{FB}$  is used as the input resistor, as shown in Figure 38, the output voltage is inversely proportional to the digital input fraction,  $D$ .

For  $D$ , which is equal to  $1 - 2^{-n}$ , the output voltage is

$$V_{OUT} = -V_{IN}/D = -V_{IN}/(1 - 2^{-n})$$

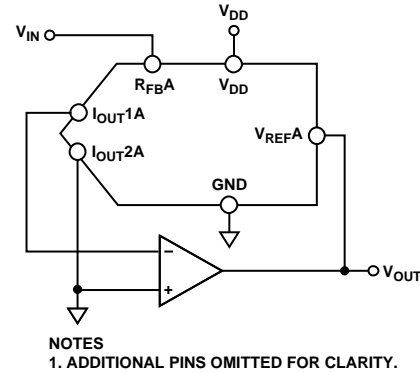


Figure 38. Current Steering DAC Used as a Divider or Programmable Gain Element

As  $D$  is reduced, the output voltage increases. For small values of the digital fraction,  $D$ , it is important to ensure the amplifier does not saturate and the required accuracy is met. For example, an 8-bit DAC driven with the binary code 0x10 (0001 0000)—that is, 16 decimal—in the circuit of Figure 38 must cause the output voltage to be 16 times  $V_{IN}$ . However, if the DAC has a linearity specification of  $\pm 0.5$  LSB,  $D$  can have a weight in the range of  $15.5/256$  to  $16.5/256$ , so that the possible output voltage is in the range of  $15.5 V_{IN}$  to  $16.5 V_{IN}$ —an error of 3%, even though the DAC itself has a maximum error of 0.2%.

DAC leakage current is also a potential source of errors in divider circuits. The leakage current must be counterbalanced by an opposite current supplied from the operational amplifier through the DAC. Because only a fraction,  $D$ , of the current into the  $V_{REFA}$  terminal is routed to the  $I_{OUT1A}$  terminal, the output voltage changes as follows:

$$\text{Output Error Voltage Due to DAC Leakage} = (\text{Leakage} \times R)/D$$

where  $R$  is the DAC resistance at the  $V_{REFA}$  terminal.

For a DAC leakage current of 10 nA,  $R = 10$  k $\Omega$ , and a gain (that is,  $1/D$ ) of 16, the error voltage is 1.6 mV.

## REFERENCE SELECTION

When selecting a reference for use with the [AD5415](#) and other devices in this series of current output DACs, pay attention to the reference output voltage temperature coefficient specification. This parameter not only affects the full-scale error, but also can affect the linearity (INL and DNL) performance. The reference temperature coefficient must be consistent with the system accuracy specifications. For example, an 8-bit system required to hold the overall specification within 1 LSB over the temperature range 0°C to 50°C dictates that the maximum system drift with temperature must be less than 78 ppm/°C. A 12-bit system with the same temperature range to overall specification within 2 LSB requires a maximum drift of 10 ppm/°C. Choosing a precision reference with a low output temperature coefficient minimizes this error source. Table 7 lists some of the references available from Analog Devices, Inc., that are suitable for use with this range of current output DACs.

## AMPLIFIER SELECTION

The primary requirement for the current steering mode is an amplifier with low input bias currents and low input offset voltage. Because of the code dependent output resistance of the DAC, the input offset voltage of an operational amplifier is multiplied by the variable gain of the circuit. A change in this noise gain between two adjacent digital fractions produces a step change in the output voltage due to the amplifier input offset voltage.

This output voltage change is superimposed on the desired change in output between the two codes and gives rise to a differential linearity error, which, if large enough, might cause the DAC to be nonmonotonic.

The input bias current of an operational amplifier also generates an offset at the voltage output as a result of the bias current flowing in the feedback resistor,  $R_{FB}$ . Most operational amplifiers have input bias currents low enough to prevent significant errors in 12-bit applications.

Common-mode rejection of the operational amplifier is important in voltage switching circuits, because it produces a code dependent error at the voltage output of the circuit. Most operational amplifiers have adequate common-mode rejection for use at 12-bit resolution.

Provided that the DAC switches are driven from true wideband low impedance sources ( $V_{IN}$  and AGND), they settle quickly. Consequently, the slew rate and settling time of a voltage switching DAC circuit is largely determined by the output operational amplifier. To obtain minimum settling time in this configuration, minimize capacitance at the  $V_{REF}$  node (the voltage output node in this application) of the DAC. This is done by using low input capacitance buffer amplifiers and careful board design.

Most single-supply circuits include ground as part of the analog signal range, which in turn requires an amplifier that can handle rail-to-rail signals. Analog Devices offers a wide range of single-supply amplifiers, as listed in Table 8 and Table 9.

Table 7. Suitable Analog Devices Precision References

| Part No. | Output Voltage (V) | Initial Tolerance (%) | Temp Drift (ppm/°C) | I <sub>SS</sub> (mA) | Output Noise (μV p-p) | Package       |
|----------|--------------------|-----------------------|---------------------|----------------------|-----------------------|---------------|
| ADR01    | 10                 | 0.05                  | 3                   | 1                    | 20                    | SOIC-8        |
| ADR01    | 10                 | 0.05                  | 9                   | 1                    | 20                    | TSOT-23, SC70 |
| ADR02    | 5                  | 0.06                  | 3                   | 1                    | 10                    | SOIC-8        |
| ADR02    | 5                  | 0.06                  | 9                   | 1                    | 10                    | TSOT-23, SC70 |
| ADR03    | 2.5                | 0.10                  | 3                   | 1                    | 6                     | SOIC-8        |
| ADR03    | 2.5                | 0.10                  | 9                   | 1                    | 6                     | TSOT-23, SC70 |
| ADR06    | 3                  | 0.10                  | 3                   | 1                    | 10                    | SOIC-8        |
| ADR06    | 3                  | 0.10                  | 9                   | 1                    | 10                    | TSOT-23, SC70 |
| ADR431   | 2.5                | 0.04                  | 3                   | 0.8                  | 3.5                   | SOIC-8        |
| ADR435   | 5                  | 0.04                  | 3                   | 0.8                  | 8                     | SOIC-8        |
| ADR391   | 2.5                | 0.16                  | 9                   | 0.12                 | 5                     | TSOT-23       |
| ADR395   | 5                  | 0.10                  | 9                   | 0.12                 | 8                     | TSOT-23       |

Table 8. Suitable Analog Devices Precision Operational Amplifiers

| Part No. | Supply Voltage (V) | V <sub>OS</sub> (Max) (μV) | I <sub>B</sub> (Max) (nA) | 0.1 Hz to 10 Hz Noise (μV p-p) | Supply Current (μA) | Package      |
|----------|--------------------|----------------------------|---------------------------|--------------------------------|---------------------|--------------|
| OP97     | ±2 to ±20          | 25                         | 0.1                       | 0.5                            | 600                 | SOIC-8       |
| OP1177   | ±2.5 to ±15        | 60                         | 2                         | 0.4                            | 500                 | MSOP, SOIC-8 |
| AD8551   | 2.7 to 5           | 5                          | 0.05                      | 1                              | 975                 | MSOP, SOIC-8 |
| AD8603   | 1.8 to 6           | 50                         | 0.001                     | 2.3                            | 50                  | TSOT         |
| AD8628   | 2.7 to 6           | 5                          | 0.1                       | 0.5                            | 850                 | TSOT, SOIC-8 |

Table 9. Suitable Analog Devices High Speed Operational Amplifiers

| Part No. | Supply Voltage (V) | BW at ACL (MHz) | Slew Rate (V/μs) | V <sub>OS</sub> (Max) (μV) | I <sub>B</sub> (Max) (nA) | Package              |
|----------|--------------------|-----------------|------------------|----------------------------|---------------------------|----------------------|
| AD8065   | 5 to 24            | 145             | 180              | 1,500                      | 6,000                     | SOIC-8, SOT-23, MSOP |
| AD8021   | ±2.5 to ±12        | 490             | 120              | 1,000                      | 10,500                    | SOIC-8, MSOP         |
| AD8038   | 3 to 12            | 350             | 425              | 3,000                      | 750                       | SOIC-8, SC70-5       |
| AD9631   | ±3 to ±6           | 320             | 1,300            | 10,000                     | 7,000                     | SOIC-8               |

**SERIAL INTERFACE**

The AD5415 has an easy to use 3-wire interface that is compatible with SPI, QSPI, MICROWIRE, and most DSP interface standards. Data is written to the device in 16-bit words. Each 16-bit word consists of four control bits and 12 data bits, as shown in Figure 39.

**Low Power Serial Interface**

To minimize the power consumption of the device, the interface only powers up fully when the device is being written to, that is, on the falling edge of SYNC. The SCLK and DIN input buffers are powered down on the rising edge of SYNC.

**DAC Control Bits C3 to C0**

Control Bits C3 to C0 allow control of various functions of the DAC, as shown in Table 11. Default settings of the DAC at power on are as follows. Data is clocked into the shift register on falling clock edges, and daisy-chain mode is enabled. The device powers on with a zero-scale load to the DAC register and I<sub>OUT</sub> lines. The DAC control bits allow the user to adjust certain features at power on. For example, daisy-chaining can be disabled when not in use, an active clock edge can be changed to a rising edge, and DAC output can be cleared to either zero scale or midscale. The user can also initiate a readback of the DAC register contents for verification purposes.

**Control Register (Control Bits = 1101)**

While maintaining software compatibility with single-channel current output DACs (AD5426/AD5433/AD5443), this DAC also features additional interface functionality. Simply set the control bits to 1101 to enter control register mode. Figure 40 shows the contents of the control register, the functions of which are described in the following sections.

**SDO Control (SDO1 and SDO2)**

The SDO bits enable the user to control the SDO output driver strength, disable the SDO output, or configure it as an open-drain driver. The strength of the SDO driver affects the timing of t<sub>12</sub> and, when stronger, allows a faster clock cycle to be used. Note that when the SDO output is disabled the daisy-chain mode is also disabled.

Table 10. SDO Control Bits

| SDO2 | SDO1 | Function                     |
|------|------|------------------------------|
| 0    | 0    | Full SDO driver              |
| 0    | 1    | Weak SDO driver              |
| 1    | 0    | SDO configured as open drain |
| 1    | 1    | Disable SDO output           |

**Daisy-Chain Control (DSY)**

DSY enables or disables daisy-chain mode. A 1 enables daisy-chain mode; a 0 disables it. When disabled, a readback request is accepted, SDO is automatically enabled, the DAC register contents of the relevant DAC are clocked out on SDO, and, when complete, SDO is disabled again.

**Hardware CLR Bit (HCLR)**

The default setting for the hardware CLR pin is to clear the registers and DAC output to zero code. A 1 in the HCLR bit clears the DAC outputs to midscale; a 0 clears them to zero scale.

**Active Clock Edge (SCLK)**

The default active clock edge is the falling edge. Write a 1 to this bit to clock data in on the rising edge; write a 0 to clock it in on the falling edge.

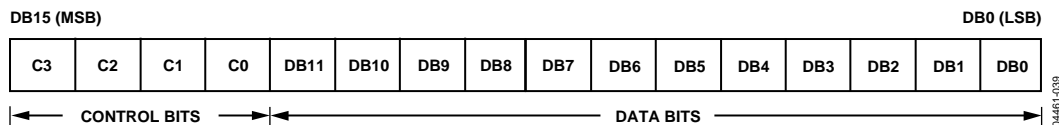


Figure 39. 12-Bit Input Shift Register Contents

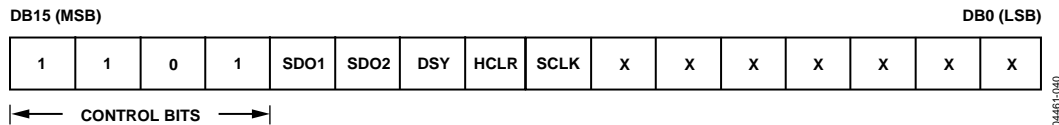


Figure 40. Control Register Loading Sequence

Table 11. DAC Control Bits

| C3 | C2 | C1 | C0 | DAC     | Function                                    |
|----|----|----|----|---------|---|
| 0  | 0  | 0  | 0  | A and B | No operation (power-on default)             |
| 0  | 0  | 0  | 1  | A       | Load and update                             |
| 0  | 0  | 1  | 0  | A       | Initiate readback                           |
| 0  | 0  | 1  | 1  | A       | Load input register                         |
| 0  | 1  | 0  | 0  | B       | Load and update                             |
| 0  | 1  | 0  | 1  | B       | Initiate readback                           |
| 0  | 1  | 1  | 0  | B       | Load input register                         |
| 0  | 1  | 1  | 1  | A and B | Update DAC outputs                          |
| 1  | 0  | 0  | 0  | A and B | Load input registers                        |
| 1  | 0  | 0  | 1  | –       | Disable daisy-chain                         |
| 1  | 0  | 1  | 0  | –       | Clock data to shift register on rising edge |
| 1  | 0  | 1  | 1  | –       | Clear DAC output to zero scale              |
| 1  | 1  | 0  | 0  | –       | Clear DAC output to midscale                |
| 1  | 1  | 0  | 1  | –       | Control word                                |
| 1  | 1  | 1  | 0  | –       | Reserved                                    |
| 1  | 1  | 1  | 1  | –       | No operation                                |

### **SYNC Function**

SYNC is an edge triggered input that acts as a frame synchronization signal and chip enable. Data can only be transferred into the device while SYNC is low. To start the serial data transfer, SYNC must be taken low, observing the minimum SYNC falling to SCLK falling edge setup time,  $t_4$ .

### **Daisy-Chain Mode**

Daisy-chain mode is the default mode at power on. To disable the daisy-chain function, write 1001 to the control word. In daisy-chain mode, the internal gating on SCLK is disabled. SCLK is continuously applied to the input shift register when SYNC is low. If more than 16 clock pulses are applied, the data ripples out of the shift register and appears on the SDO line. This data is clocked out on the rising edge of SCLK and is valid for the next device on the falling edge of SCLK (default). By connecting this line to the SDIN input on the next device in the chain, a multidevice interface is constructed. For each device in the system, 16 clock pulses are required. Therefore, the total number of clock cycles must equal  $16N$ , where  $N$  is the total number of devices in the chain. (See Figure 5.)

When the serial transfer to all devices is complete, SYNC must be taken high. This prevents additional data from being clocked into the input shift register. A burst clock containing the exact number of clock cycles can be used, after which SYNC is taken high. After the rising edge of SYNC, data is automatically transferred from each device input shift register to the addressed DAC.

When control bits are 0000, the device is in no-operation mode. This might be useful in daisy-chain applications where the user does not want to change the settings of a particular DAC in the chain. Write 0000 to the control bits for that DAC, and subsequent data bits are ignored.

### **Standalone Mode**

After power on, writing 1001 to the control word disables daisy-chain mode. The first falling edge of SYNC resets the serial clock counter to ensure that the correct number of bits are shifted in and out of the serial shift registers. A SYNC edge during the 16-bit write cycle causes the device to abort the current write cycle.

After the falling edge of the 16th SCLK pulse, data is automatically transferred from the input shift register to the DAC. For another serial transfer to take place, the counter must be reset by the falling edge of SYNC.

### **LDAC Function**

The LDAC function allows asynchronous and synchronous updates to the DAC output. The DAC is asynchronously updated when this signal goes low. Alternatively, if this line is held permanently low, an automatic or synchronous update mode is selected, whereby the DAC is updated on the 16th clock falling edge when the device is in standalone mode, or on the rising edge of SYNC when the device is in daisy-chain mode.

### **Software LDAC Function**

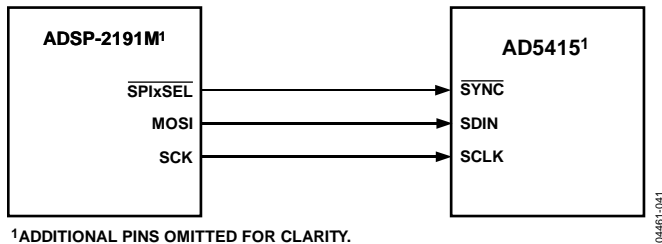
The load and update mode also functions as a software update function, irrespective of the voltage level on the LDAC pin.

**MICROPROCESSOR INTERFACING**

Microprocessor interfacing to the AD5415 DAC is through a serial bus that uses standard protocol compatible with micro-controllers and DSP processors. The communication channel is a 3-wire interface consisting of a clock signal, a data signal, and a synchronization signal. The AD5415 requires a 16-bit word, with the default being data valid on the falling edge of SCLK; however, this is changeable using the control bits in the data-word.

**ADSP-21xx to AD5415 Interface**

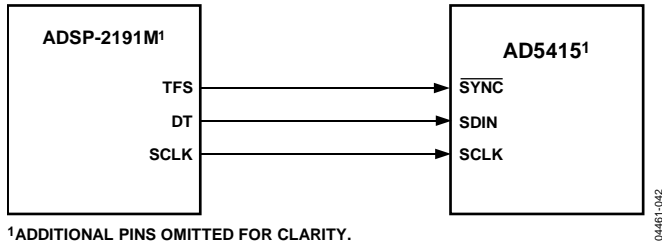
The ADSP-21xx family of DSPs is easily interfaced to the AD5415 DAC without the need for extra glue logic. Figure 41 is an example of an SPI interface between the DAC and the ADSP-2191M. SCK of the DSP drives the serial data line, SDIN. SYNC is driven from a port line, in this case SPIxSEL.



<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY. 04461-041

Figure 41. ADSP-2191M SPI to AD5415 Interface

A serial interface between the DAC and DSP SPORT is shown in Figure 42. In this interface example, SPORT0 is used to transfer data to the DAC shift register. Transmission is initiated by writing a word to the Tx register after SPORT is enabled. In a write sequence, data is clocked out on each rising edge of the DSP serial clock and clocked into the DAC input shift register on the falling edge of the SCLK. The update of the DAC output takes place on the rising edge of the SYNC signal.



<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY. 04461-042

Figure 42. ADSP-2191M SPORT to AD5415 Interface

Communication between two devices at a given clock speed is possible when the following specifications are compatible: frame sync delay and frame sync setup and hold, data delay and data setup and hold, and SCLK width. The DAC interface expects a  $t_4$  (SYNC falling edge to SCLK falling edge setup time) of 13 ns minimum. See the ADSP-21xx device family for information on clock and frame SYNC frequencies for the SPORT register.

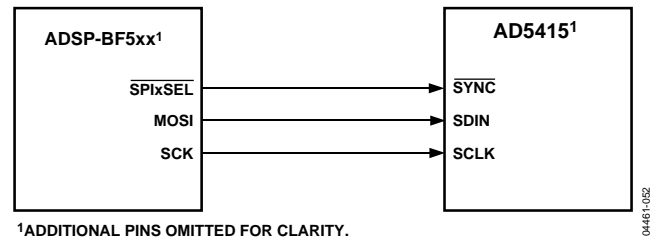
Table 12 shows the setup for the SPORT control register.

**Table 12. SPORT Control Register Setup**

| Name   | Setting | Description             |
|--------|---------|-------------------------|
| TFSW   | 1       | Alternate framing       |
| INVTFS | 1       | Active low frame signal |
| DTYPE  | 00      | Right justify data      |
| ISCLK  | 1       | Internal serial clock   |
| TFSR   | 1       | Frame every word        |
| ITFS   | 1       | Internal framing signal |
| SLEN   | 1111    | 16-bit data-word        |

**ADSP-BF504 to ADSP-BF592 Device Family to AD5415 Interface**

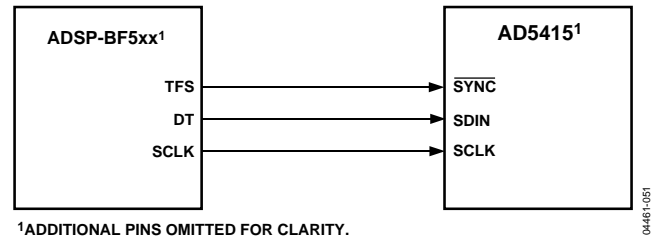
The ADSP-BF504 to ADSP-BF592 device family of processors has an SPI-compatible port that enables the processor to communicate with SPI-compatible devices. A serial interface between the BlackFin® processor and the AD5415 DAC is shown in Figure 43. In this configuration, data is transferred through the MOSI (master output, slave input) pin. SYNC is driven by the SPIxSEL pin, which is a reconfigured programmable flag pin.



<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY. 04461-052

Figure 43. ADSP-BF504 to ADSP-BF592 Device Family to AD5415 Interface (ADSP-BFxx Denotes the ADSP-BF504 to ADSP-BF592)

The ADSP-BF504 to ADSP-BF592 device family processors incorporate channel synchronous serial ports (SPORT). A serial interface between the DAC and the DSP SPORT is shown in Figure 44. When SPORT is enabled, initiate transmission by writing a word to the Tx register. The data is clocked out on each rising edge of the DSP serial clock and clocked into the DAC input shift register on the falling edge of the SCLK. The DAC output is updated by using the transmit frame synchronization (TFS) line to provide a SYNC signal.

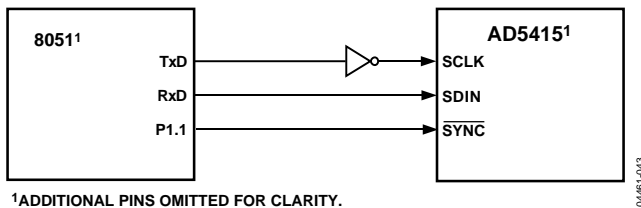


<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY. 04461-051

Figure 44. ADSP-BF504 to ADSP-BF592 Device Family SPORT to AD5415 Interface (ADSP-BFxx Denotes the ADSP-BF504 to ADSP-BF592)

### 80C51/80L51 to AD5415 Interface

A serial interface between the DAC and the 80C51 is shown in Figure 45. TxD of the 80C51 drives SCLK of the DAC serial interface, and RxD drives the serial data line, SDIN. P1.1 is a bit-programmable pin on the serial port and is used to drive SYNC. When data is to be transmitted to the switch, P1.1 is taken low. The 80C51/80L51 only transmits data in 8-bit bytes; therefore, only eight falling clock edges occur in the transmit cycle. To load data correctly to the DAC, P1.1 is left low after the first eight bits are transmitted, and a second write cycle is initiated to transmit the second byte of data. Data on RxD is clocked out of the microcontroller on the rising edge of TxD and is valid on the falling edge of TxD. As a result, no glue logic is required between the DAC and microcontroller interface. P1.1 is taken high following the completion of this cycle. The 80C51 provides the LSB of the SBUF register as the first bit in the data stream. The DAC input register requires the data with the MSB as the first bit received. The transmit routine must take this into account.



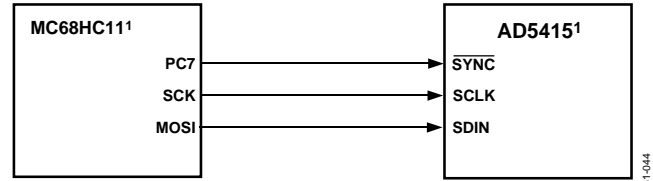
<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY.

Figure 45. 80C51/80L51 to AD5415 Interface

### MC68HC11 to AD5415 Interface

Figure 46 is an example of a serial interface between the DAC and the MC68HC11 microcontroller (Motorola). The serial peripheral interface (SPI) on the MC68HC11 is configured for master mode (MSTR) = 1, clock polarity bit (CPOL) = 0, and the clock phase bit (CPHA) = 1. The SPI is configured by writing to the SPI control register (SPCR); see the *68HC11 User Manual*. SCK of the 68HC11 drives the SCLK of the DAC interface; the MOSI output drives the serial data line (SDIN) of the DAC.

The SYNC signal is derived from a port line (PC7). When data is transmitted to the AD5415, the SYNC line is taken low (PC7). Data appearing on the MOSI output is valid on the falling edge of SCK. Serial data from the 68HC11 is transmitted in 8-bit bytes with only eight falling clock edges occurring in the transmit cycle. Data is transmitted MSB first. To load data to the DAC, leave PC7 low after the first eight bits are transferred and perform a second serial write operation to the DAC. PC7 is taken high at the end of this procedure.



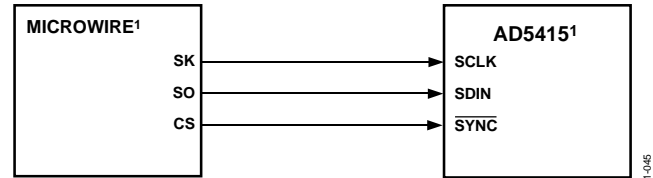
<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY.

Figure 46. MC68HC11 to AD5415 Interface

If the user wants to verify the data previously written to the input shift register, the SDO line can be connected to MISO of the MC68HC11, and, with SYNC low, the shift register clocks data out on the rising edges of SCLK.

### MICROWIRE to AD5415 Interface

Figure 47 shows an interface between the DAC and any MICROWIRE-compatible device. Serial data is shifted out on the falling edge of the serial clock, SK, and is clocked into the DAC input shift register on the rising edge of SK, which corresponds to the falling edge of the DAC SCLK.

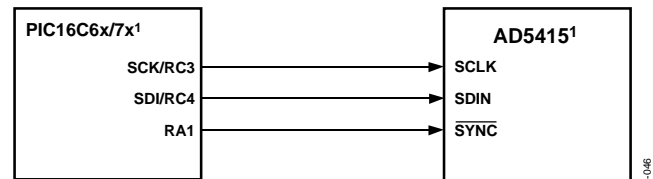


<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY.

Figure 47. MICROWIRE to AD5415 Interface

### PIC16C6x/PIC16C7x to AD5415 Interface

The PIC16C6x/PIC16C7x (Microchip) synchronous serial port (SSP) is configured as an SPI master with the clock polarity bit (CKP) = 0. This is done by writing to the synchronous serial port control register (SSPCON). In this example, the input/output port RA1 is used to provide a SYNC signal and enable the serial port of the DAC. This microcontroller transfers only eight bits of data during each serial transfer operation; therefore, two consecutive write operations are required. Figure 48 shows the connection diagram.



<sup>1</sup>ADDITIONAL PINS OMITTED FOR CLARITY.

Figure 48. PIC16C6x/PIC16C7x to AD5415 Interface

### PCB LAYOUT AND POWER SUPPLY DECOUPLING

In any circuit where accuracy is important, careful consideration of the power supply and ground return layout ensures the rated performance. The PCB on which the AD5415 is mounted must be designed so that the analog and digital sections are separated and confined to certain areas of the board. If the DAC is in a system where multiple devices require an AGND to DGND connection, the connection must be made at one point only. The star ground point must be established as close as possible to the device.

The DAC must have ample supply bypassing of 10  $\mu\text{F}$  in parallel with 0.1  $\mu\text{F}$  on the supply located as close as possible to the package, ideally right up against the device. The 0.1  $\mu\text{F}$  capacitor must have low effective series resistance (ESR) and low effective series inductance (ESI), like the common ceramic types of capacitors that provide a low impedance path to ground at high frequencies, to handle transient currents due to internal logic switching. Low ESR 1  $\mu\text{F}$  to 10  $\mu\text{F}$  tantalum or electrolytic capacitors must also be applied at the supplies to minimize transient disturbance and filter out low frequency ripple.

Components, such as clocks, that produce fast switching signals must be shielded with digital ground to avoid radiating noise to other parts of the board, and they must never be run near the reference inputs.

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

It is good practice to use a compact, minimum lead length PCB layout design. Leads to the input must be as short as possible to minimize IR drops and stray inductance.

The PCB metal traces between  $V_{\text{REF}}$  and  $R_{\text{FB}}$  must also be matched to minimize gain error. To maximize high frequency performance, the I-to-V amplifier must be located as close as possible to the device.



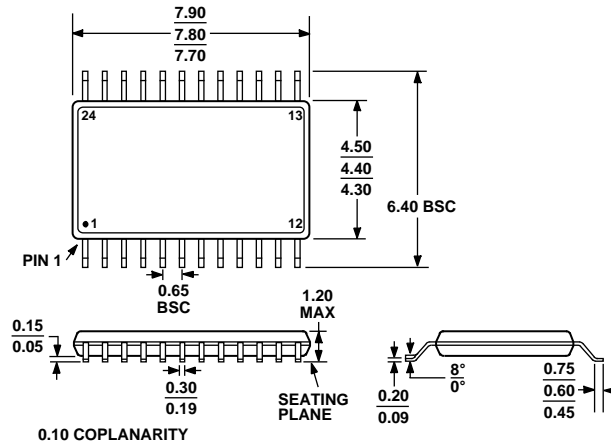
## OVERVIEW OF THE AD5424 TO AD5547 DEVICES

Table 13.

| Part No. | Resolution | No. DACs | INL (LSB) | Interface | Package <sup>1</sup> | Features                                     |
|----------|------------|----------|-----------|-----------|----------------------|--|
| AD5424   | 8          | 1        | ±0.25     | Parallel  | RU-16, CP-20         | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5426   | 8          | 1        | ±0.25     | Serial    | RM-10                | 10 MHz BW, 50 MHz serial                     |
| AD5428   | 8          | 2        | ±0.25     | Parallel  | RU-20                | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5429   | 8          | 2        | ±0.25     | Serial    | RU-10                | 10 MHz BW, 50 MHz serial                     |
| AD5450   | 8          | 1        | ±0.25     | Serial    | UJ-8                 | 10 MHz BW, 50 MHz serial                     |
| AD5432   | 10         | 1        | ±0.5      | Serial    | RM-10                | 10 MHz BW, 50 MHz serial                     |
| AD5433   | 10         | 1        | ±0.5      | Parallel  | RU-20, CP-20         | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5439   | 10         | 2        | ±0.5      | Serial    | RU-16                | 10 MHz BW, 50 MHz serial                     |
| AD5440   | 10         | 2        | ±0.5      | Parallel  | RU-24                | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5451   | 10         | 1        | ±0.25     | Serial    | UJ-8                 | 10 MHz BW, 50 MHz serial                     |
| AD5443   | 12         | 1        | ±1        | Serial    | RM-10                | 10 MHz BW, 50 MHz serial                     |
| AD5444   | 12         | 1        | ±0.5      | Serial    | RM-8                 | 10 MHz BW, 50 MHz serial                     |
| AD5415   | 12         | 2        | ±1        | Serial    | RU-24                | 10 MHz BW, 50 MHz serial                     |
| AD5405   | 12         | 2        | ±1        | Parallel  | CP-40                | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5445   | 12         | 2        | ±1        | Parallel  | RU-20, CP-20         | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5447   | 12         | 2        | ±1        | Parallel  | RU-24                | 10 MHz BW, 17 ns $\overline{CS}$ pulse width |
| AD5449   | 12         | 2        | ±1        | Serial    | RU-16                | 10 MHz BW, 50 MHz serial                     |
| AD5452   | 12         | 1        | ±0.5      | Serial    | UJ-8, RM-8           | 10 MHz BW, 50 MHz serial                     |
| AD5446   | 14         | 1        | ±1        | Serial    | RM-8                 | 10 MHz BW, 50 MHz serial                     |
| AD5453   | 14         | 1        | ±2        | Serial    | UJ-8, RM-8           | 10 MHz BW, 50 MHz serial                     |
| AD5553   | 14         | 1        | ±1        | Serial    | RM-8                 | 4 MHz BW, 50 MHz serial clock                |
| AD5556   | 14         | 1        | ±1        | Parallel  | RU-28                | 4 MHz BW, 20 ns $\overline{WR}$ pulse width  |
| AD5555   | 14         | 2        | ±1        | Serial    | RM-8                 | 4 MHz BW, 50 MHz serial clock                |
| AD5557   | 14         | 2        | ±1        | Parallel  | RU-38                | 4 MHz BW, 20 ns $\overline{WR}$ pulse width  |
| AD5543   | 16         | 1        | ±2        | Serial    | RM-8                 | 4 MHz BW, 50 MHz serial clock                |
| AD5546   | 16         | 1        | ±2        | Parallel  | RU-28                | 4 MHz BW, 20 ns $\overline{WR}$ pulse width  |
| AD5545   | 16         | 2        | ±2        | Serial    | RU-16                | 4 MHz BW, 50 MHz serial clock                |
| AD5547   | 16         | 2        | ±2        | Parallel  | RU-38                | 4 MHz BW, 20 ns $\overline{WR}$ pulse width  |

<sup>1</sup> RU = TSSOP, CP = LFCSP, RM = MSOP, UJ = TSOT.

OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-153-AD

Figure 49. 24-Lead Thin Shrink Small Outline Package [TSSOP] (RU-24)

Dimensions shown in millimeters

ORDERING GUIDE

| Model <sup>1</sup> | Resolution | INL (LSB) | Temperature Range | Package Description | Package Option |
|--------------------|------------|-----------|-------------------|---------------------|----------------|
| AD5415YRUZ         | 12         | ±1        | -40°C to +125°C   | 24-Lead TSSOP       | RU-24          |
| AD5415YRUZ-REEL    | 12         | ±1        | -40°C to +125°C   | 24-Lead TSSOP       | RU-24          |
| AD5415YRUZ-REEL7   | 12         | ±1        | -40°C to +125°C   | 24-Lead TSSOP       | RU-24          |
| EV-AD5415/49SDZ    |            |           |                   | Evaluation Board    |                |

<sup>1</sup> Z = RoHS Compliant Part.

**NOTES**

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