

### FEATURES

- ±0.5 LSB INL
- 2.5 V to 5.5 V supply operation
- ±10 V reference input
- Extended temperature range: -40°C to +125°C
- 10-lead MSOP package
- Pin-compatible 12-bit current output DAC
- 50 MHz serial interface
- Guaranteed monotonic
- 4-quadrant multiplication
- Power-on reset with brownout detection
- <0.4 µA typical current consumption

### APPLICATIONS

- Portable battery-powered applications
- Waveform generators
- Analog processing
- Instrumentation applications
- Programmable amplifiers and attenuators
- Digitally controlled calibration
- Programmable filters and oscillators
- Composite video
- Ultrasound
- Gain, offset, and voltage trimming
- Automotive radar

### GENERAL DESCRIPTION

The AD5444<sup>1</sup> is a CMOS 12-bit, current output digital-to-analog converter. The device operates from a single 2.5 V to 5.5 V power supply, making it suited to battery-powered applications as well as many other applications.

The DAC uses a double-buffered 3-wire serial interface that is compatible with SPI®, QSPI™, MICROWIRE™, and most DSP interface standards. On power-up, the internal shift register and latches are filled with 0s, and the DAC output is at zero scale. As a result of manufacture on a CMOS submicron process, the part offers excellent 4-quadrant multiplication characteristics.

The applied external reference input voltage ( $V_{REF}$ ) determines the full-scale output current. The part can handle ±10 V inputs on the reference despite operating from a single-supply power supply of 2.5 V to 5.5 V. An integrated feedback resistor ( $R_{FB}$ ) provides temperature tracking and full-scale voltage output when combined with an external current-to-voltage precision amplifier. The AD5444 DAC is available in a small 10-lead MSOP package that is pin compatible with the AD5425/AD5426/AD5432/AD5443 family of DACs.

<sup>1</sup> US Patent Number 5,689,257.

### FUNCTIONAL BLOCK DIAGRAM

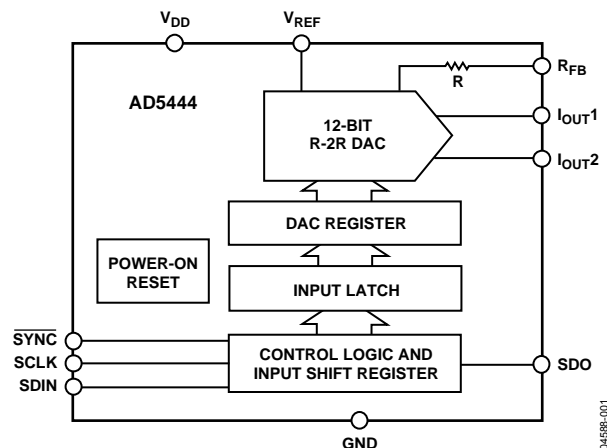


Figure 1.

### Rev. 0

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**REVISION HISTORY****10/04—Revision 0: Initial Version**

## SPECIFICATIONS

Temperature range for Y Version:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

$V_{\text{DD}} = 2.5\text{ V}$  to  $5.5\text{ V}$ ,  $V_{\text{REF}} = 10\text{ V}$ ,  $I_{\text{OUT}2} = 0\text{ V}$ . All specifications  $T_{\text{MIN}}$  to  $T_{\text{MAX}}$ , unless otherwise noted.

The dc performance was measured with OP177; the ac performance was measured with AD8038, unless otherwise noted.

**Table 1.**

Parameter	Min	Typ	Max	Unit	Conditions
<b>STATIC PERFORMANCE</b>					
Resolution			12	Bits	Guaranteed monotonic
Relative Accuracy			$\pm 0.5$	LSB	
Differential Nonlinearity			$\pm 1$	LSB	
Total Unadjusted Error (TUE)			$\pm 1$	LSB	
Gain Error			$\pm 0.5$	LSB	
Gain Error Temp Coefficient <sup>1</sup>		$\pm 5$		ppm FSR/ $^{\circ}\text{C}$	
Output Leakage Current			$\pm 1$	nA	
			$\pm 10$	nA	Data = 0x0000, $T_{\text{A}} = -40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$ , $I_{\text{OUT}1}$
<b>REFERENCE INPUT<sup>1</sup></b>					
Reference Input Range		$\pm 10$		V	Input resistance TC = $-50\text{ ppm}/^{\circ}\text{C}$ Input resistance TC = $-50\text{ ppm}/^{\circ}\text{C}$
$V_{\text{REF}}$ Input Resistance	7	9	11	k $\Omega$	
$R_{\text{FB}}$ Feedback Resistance	7	9	11	k $\Omega$	
Input Capacitance					
Zero-Scale Code		18	22	pF	
Full-Scale Code		18	22	pF	
<b>DIGITAL INPUTS/OUTPUTS<sup>1</sup></b>					
Input High Voltage, $V_{\text{IH}}$	2.0			V	$V_{\text{DD}} = 3.6\text{ V}$ to $5\text{ V}$
	1.7			V	$V_{\text{DD}} = 2.5\text{ V}$ to $3.6\text{ V}$
Input Low Voltage, $V_{\text{IL}}$			0.8	V	$V_{\text{DD}} = 2.7\text{ V}$ to $5.5\text{ V}$
			0.7	V	$V_{\text{DD}} = 2.5\text{ V}$ to $2.7\text{ V}$
Output High Voltage, $V_{\text{OH}}$	$V_{\text{DD}} - 1$			V	$V_{\text{DD}} = 4.5\text{ V}$ to $5\text{ V}$ , $I_{\text{SOURCE}} = 200\text{ }\mu\text{A}$
	$V_{\text{DD}} - 0.5$			V	$V_{\text{DD}} = 2.5\text{ V}$ to $3.6\text{ V}$ , $I_{\text{SOURCE}} = 200\text{ }\mu\text{A}$
Output Low Voltage, $V_{\text{OL}}$			0.4	V	$V_{\text{DD}} = 4.5\text{ V}$ to $5\text{ V}$ , $I_{\text{SINK}} = 200\text{ }\mu\text{A}$
			0.4	V	$V_{\text{DD}} = 2.5\text{ V}$ to $3.6\text{ V}$ , $I_{\text{SINK}} = 200\text{ }\mu\text{A}$
Input Leakage Current, $I_{\text{IL}}$			$\pm 1$	nA	$T_{\text{A}} = 25^{\circ}\text{C}$
			$\pm 10$	nA	$T_{\text{A}} = -40^{\circ}\text{C}$ to $+125^{\circ}\text{C}$
Input Capacitance			10	pF	
<b>DYNAMIC PERFORMANCE<sup>1</sup></b>					
Reference Multiplying BW	10			MHz	$V_{\text{REF}} = \pm 3.5\text{ V}$ , DAC loaded all 1s
Output Voltage Settling Time					$V_{\text{REF}} = 10\text{ V}$ , $R_{\text{LOAD}} = 100\text{ }\Omega$ , DAC latch alternately loaded with 0s and 1s
Measured to $\pm 1\text{ mV}$ of FS		100	110	ns	
Measured to $\pm 4\text{ mV}$ of FS		24	40	ns	
Measured to $\pm 16\text{ mV}$ of FS		16	33	ns	
Digital Delay		20	40	ns	Interface delay time
10% to 90% Settling Time		10	30	ns	Rise and fall time, $V_{\text{REF}} = 10\text{ V}$ , $R_{\text{LOAD}} = 100\text{ }\Omega$ , 1 LSB change around major carry, $V_{\text{REF}} = 0\text{ V}$
Digital-to-Analog Glitch Impulse		2		nV-s	
Output Capacitance					
$I_{\text{OUT}1}$		13		pF	DAC latches loaded with all 0s
		28		pF	DAC latches loaded with all 1s
$I_{\text{OUT}2}$		18		pF	DAC latches loaded with all 0s
		5		pF	DAC latches loaded with all 1s
Digital Feedthrough		0.5		nV-s	Feedthrough to DAC output with $\overline{\text{CS}}$ high and alternate loading of all 0s and all 1s

# AD5444

Parameter	Min	Typ	Max	Unit	Conditions
Analog THD		83		dB	$V_{REF} = 3.5\text{ V p-p}$ , all 1s loaded, $f = 1\text{ kHz}$
Digital THD					Clock = 1 MHz, $V_{REF} = 3.5\text{ V}$
50 kHz $f_{OUT}$		71		dB	50 kHz $f_{OUT}$
20 kHz $f_{OUT}$		77		dB	20 kHz $f_{OUT}$
Output Noise Spectral Density		25		nV/ $\sqrt{\text{Hz}}$	@ 1 kHz
SFDR Performance (Wideband)					Clock = 10 MHz, $V_{REF} = 3.5\text{ V}$
50 kHz $f_{OUT}$		78		dB	
20 kHz $f_{OUT}$		74		dB	
SFDR Performance (Narrow-Band)					Clock = 1 MHz, $V_{REF} = 3.5\text{ V}$
50 kHz $f_{OUT}$		87		dB	
20 kHz $f_{OUT}$		85		dB	
Intermodulation Distortion		79		dB	$f_1 = 20\text{ kHz}$ , $f_2 = 25\text{ kHz}$ , Clock = 1 MHz, $V_{REF} = 3.5\text{ V}$
<b>POWER REQUIREMENTS</b>					
Power Supply Range	2.5		5.5	V	
$I_{DD}$		0.4	10	$\mu\text{A}$	$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$ , logic inputs = 0 V or $V_{DD}$
			0.6	$\mu\text{A}$	$T_A = 25^\circ\text{C}$ , logic inputs = 0 V or $V_{DD}$
Power Supply Sensitivity <sup>1</sup>			0.001	%/%	$\Delta V_{DD} = \pm 5\%$

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

# TIMING CHARACTERISTICS

Temperature range for Y Version: -40°C to +125°C. See Figure 2.

Guaranteed by design and characterization, not subject to production test.

All input signals are specified with  $t_r = t_f = 1$  ns (10% to 90% of  $V_{DD}$ ) and timed from a voltage level of  $(V_{IL} + V_{IH})/2$ .

$V_{REF} = 5$  V,  $I_{OUT2} = 0$  V.

All specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

Table 2.

Parameter	$V_{DD} = 4.5$ V to 5.5 V	$V_{DD} = 2.5$ V to 5.5 V	Unit	Conditions / Comments
$f_{SCLK}$	50	50	MHz max	Maximum Clock Frequency
$t_1$	20	20	ns min	SCLK Cycle Time
$t_2$	8	8	ns min	SCLK High Time
$t_3$	8	8	ns min	SCLK Low Time
$t_4$	8	8	ns min	$\overline{SYNC}$ Falling Edge to SCLK Active Edge Setup Time
$t_5$	5	5	ns min	Data Setup Time
$t_6$	4.5	4.5	ns min	Data Hold Time
$t_7$	5	5	ns min	$\overline{SYNC}$ Rising Edge to SCLK Active Edge
$t_8$	30	30	ns min	Minimum $\overline{SYNC}$ High Time
$t_9$	23	30	ns min	SCLK Active Edge to SDO Valid

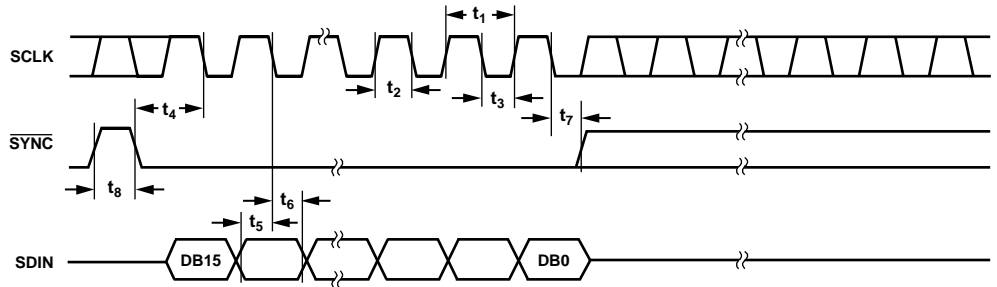
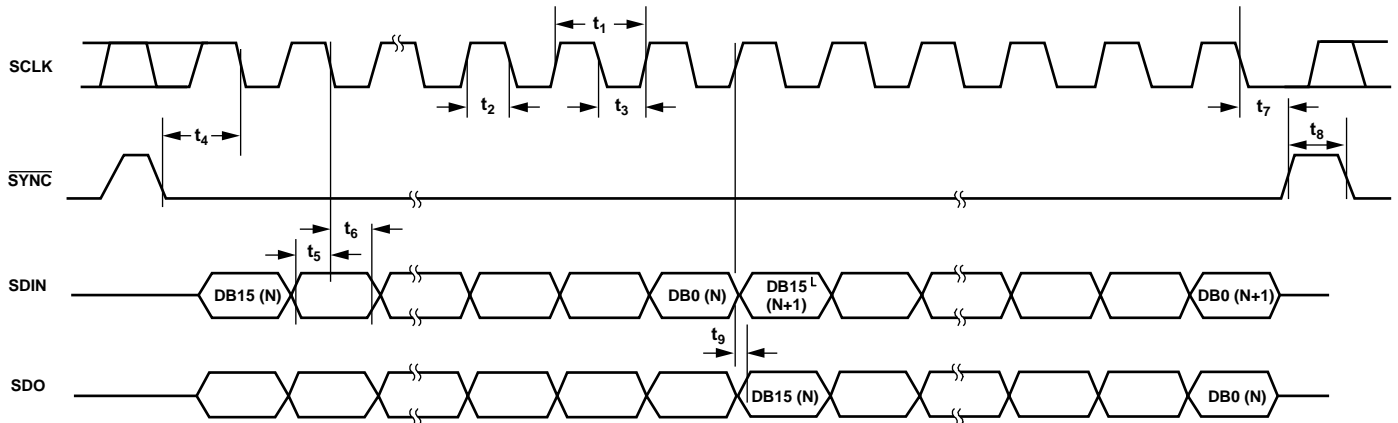


Figure 2. Standalone Timing Diagram



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

Figure 3. Daisy-Chain Timing Diagram

## ABSOLUTE MAXIMUM RATINGS

T<sub>A</sub> = 25°C, unless otherwise noted.

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

**Table 3.**

Parameter	Rating
V <sub>DD</sub> to GND	-0.3 V to +7 V
V <sub>REF</sub> , R <sub>FEB</sub> to GND	-12 V to +12 V
I <sub>OUT1</sub> , I <sub>OUT2</sub> to GND	-0.3 V to +7 V
Logic Inputs and Output <sup>1</sup>	-0.3 V to V <sub>DD</sub> + 0.3 V
Input Current to Any Pin except Supplies	±10 mA
Operating Temperature Range	
Extended (Y Version)	-40°C to +125°C
Storage Temperature Range	-65°C to +150°C
Junction Temperature	150°C
10-lead MSOP θ <sub>JA</sub> Thermal Impedance	206°C/W
Lead Temperature, Soldering (10 s)	300°C
IR Reflow, Peak Temperature (<20 s)	235°C

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

## ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

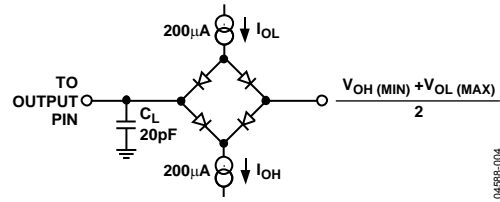


Figure 4. Load Circuit for SDO Timing Specifications

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those listed in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability. Only one absolute maximum rating may be applied at any one time.



## PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

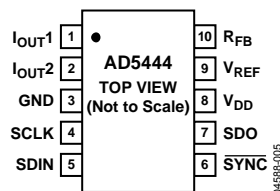


Figure 5. Pin Configuration MSOP (RM-10)

Table 4. Pin Function Descriptions

Pin No.	Mnemonic	Function
1	I <sub>OUT1</sub>	DAC Current Output.
2	I <sub>OUT2</sub>	DAC Analog Ground. This pin should normally be tied to the analog ground of the system.
3	GND	Ground Pin.
4	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.
5	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.
6	$\overline{\text{SYNC}}$	Active Low Control Input. This is the frame synchronization signal for the input data. When $\overline{\text{SYNC}}$ is taken low, data is loaded to the shift register on the active edge of the following clocks. The output updates on the rising edge of $\overline{\text{SYNC}}$ .
7	SDO	Serial Data Output. This pin allows a number of parts to be daisy-chained. By default, data is clocked into the shift register on the falling edge and 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.
8	V <sub>DD</sub>	Positive Power Supply Input. This part can be operated from a supply of 2.5 V to 5.5 V.
9	V <sub>REF</sub>	DAC Reference Voltage Input.
10	R <sub>FB</sub>	DAC Feedback Resistor. Establishes voltage output for the DAC by connecting to an external amplifier output.

## TERMINOLOGY

### Relative Accuracy

Relative accuracy or endpoint nonlinearity is a measure of the maximum deviation from a straight line passing through the endpoints of the DAC transfer function. It is measured after adjusting for zero scale and full scale and is normally expressed in LSBs or as a percentage of full-scale reading.

### Differential Nonlinearity

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

### Gain Error

Gain error or full-scale error is 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. Gain error of the DAC is adjustable to zero with external resistance.

### Output Leakage Current

Output leakage current is current that flows in the DAC ladder switches when these 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 in 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 it takes 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. The settling time specification includes the digital delay from the  $\overline{SYNC}$  rising edge to the full-scale output change.

### 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-s or nV-s, depending upon 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 device's digital inputs can be capacitively coupled through the device to show up as noise on the  $I_{OUT}$  pins and, subsequently, into 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.

### 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 such as second to fifth are included.

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

### Digital Intermodulation Distortion

Second-order intermodulation (IMD) measurements are the relative magnitudes of the  $f_a$  and  $f_b$  tones generated digitally by the DAC and the second-order products at  $2f_a - f_b$  and  $2f_b - f_a$ .

### Compliance Voltage Range

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

### Spurious-Free Dynamic Range (SFDR)

The usable dynamic range of a DAC before spurious noise interferes or distorts the fundamental signal. SFDR is the measure of difference in amplitude between the fundamental and the largest harmonically or nonharmonically related spur from dc to full Nyquist bandwidth (half the DAC sampling rate or  $f_s/2$ ). Narrow-band SFDR is a measure of SFDR over an arbitrary window size, in this case 50% of the fundamental. Digital SFDR is a measure of the usable dynamic range of the DAC when the signal is a digitally generated sine wave.



# TYPICAL PERFORMANCE CHARACTERISTICS

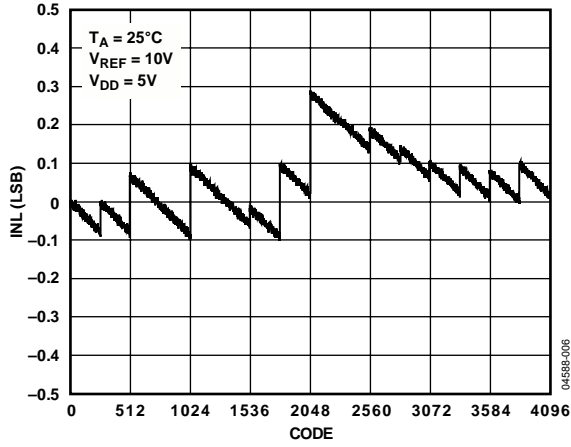


Figure 6. INL vs. Code

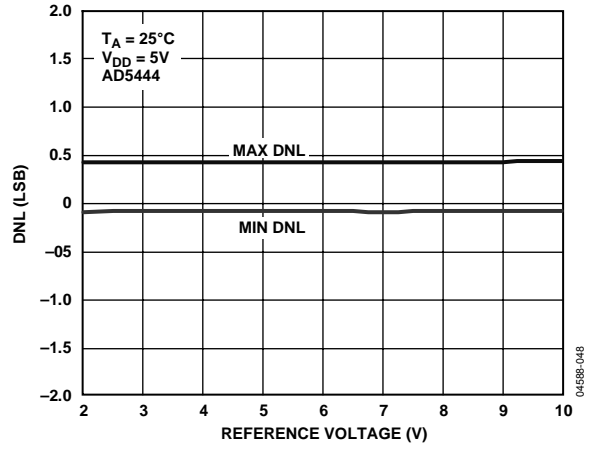


Figure 9. DNL vs. Reference Voltage

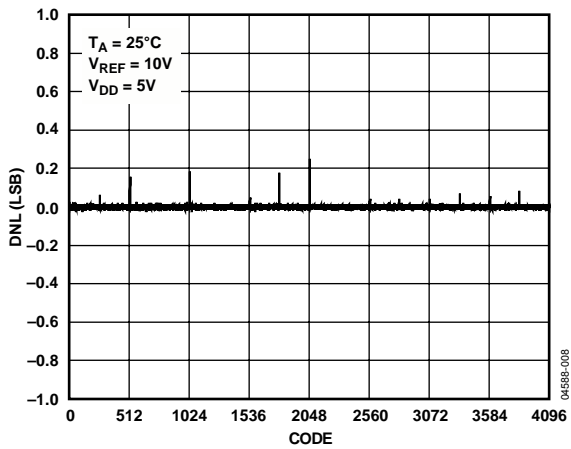


Figure 7. DNL vs. Code

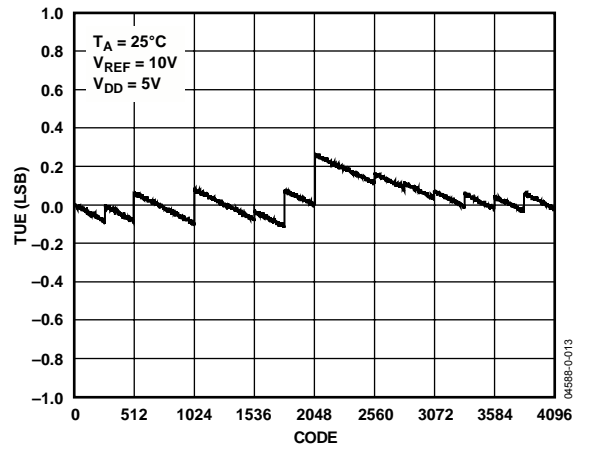


Figure 10. TUE vs. Code

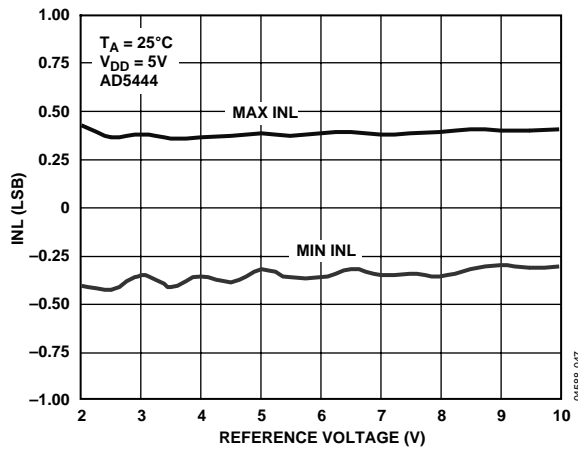


Figure 8. INL vs. Reference Voltage

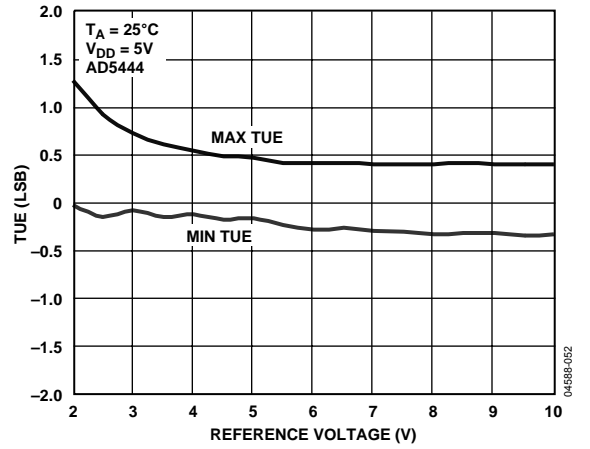


Figure 11. TUE vs. Reference Voltage

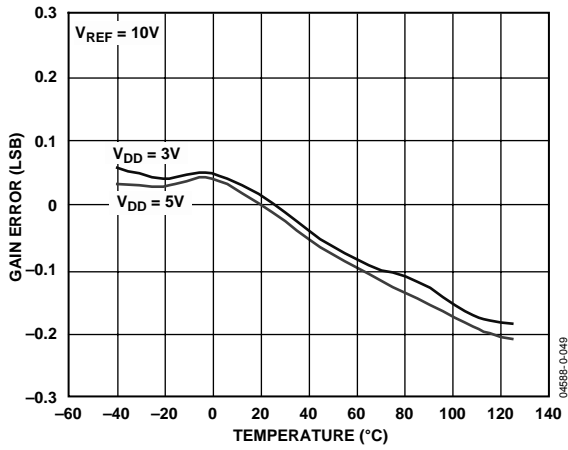


Figure 12. Gain Error (LSB) vs. Temperature

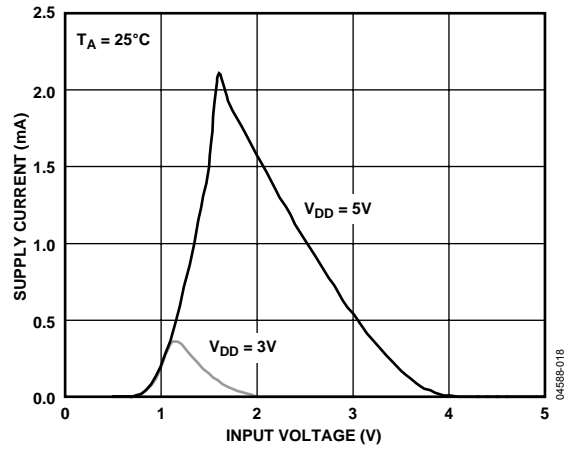


Figure 15. Supply Current vs. Logic Input Voltage

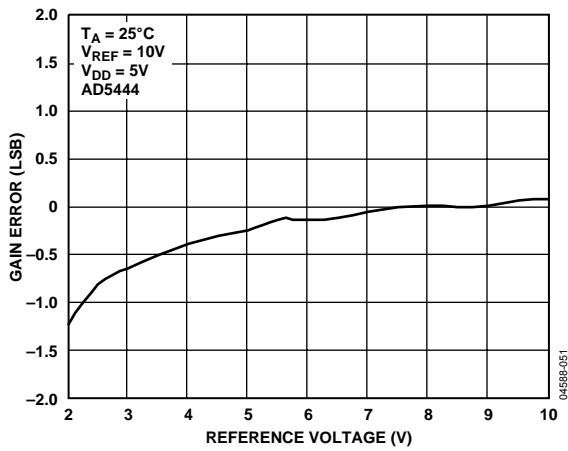


Figure 13. Gain Error (LSB) vs. Reference Voltage

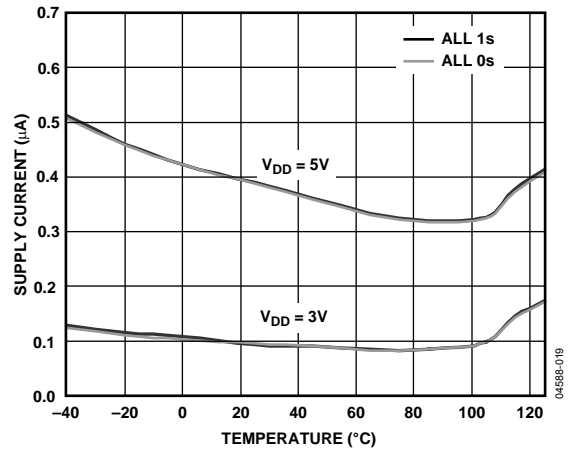


Figure 16. Supply Current vs. Temperature

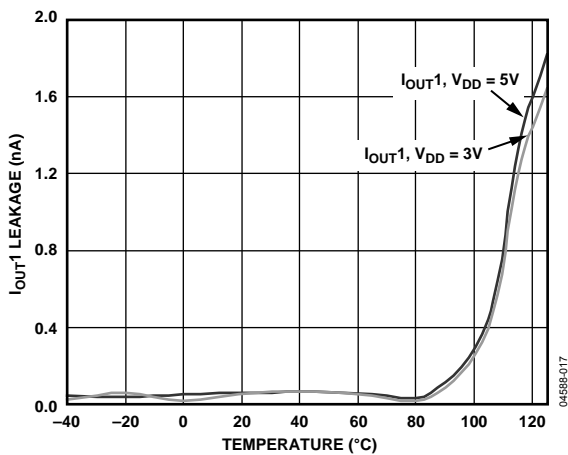


Figure 14.  $I_{OUT1}$  Leakage Current vs. Temperature

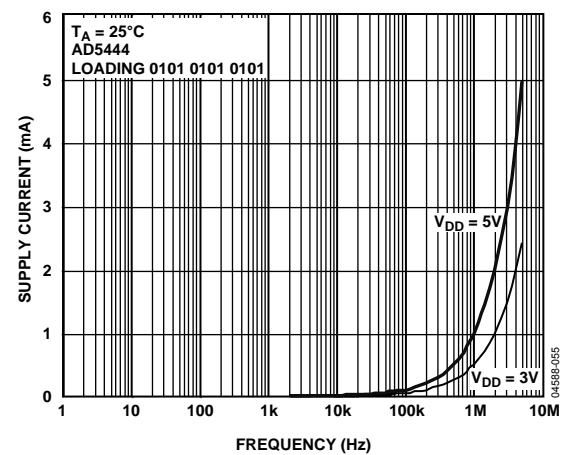


Figure 17. Supply Current vs. Update Rate

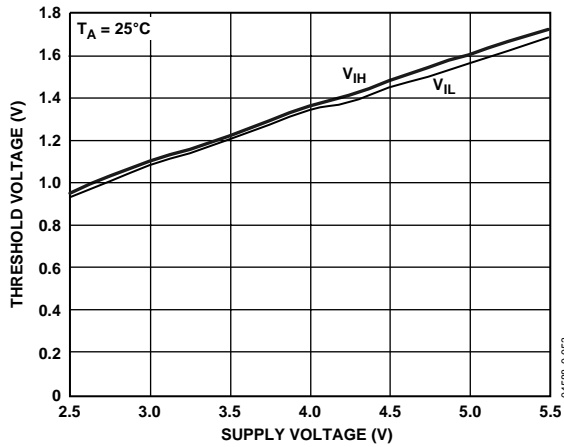


Figure 18. Threshold Voltage vs. Supply Voltage

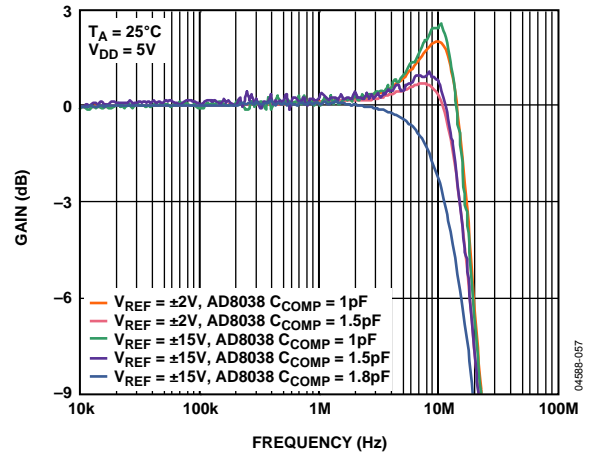


Figure 21. Reference Multiplying Bandwidth vs. Frequency and Compensation Capacitor

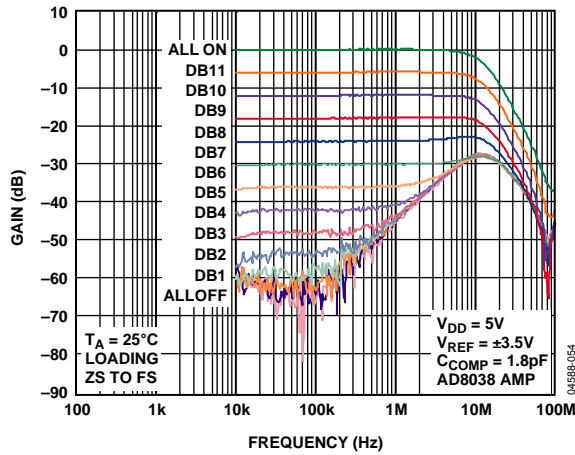


Figure 19. Reference Multiplying Bandwidth vs. Frequency and Code

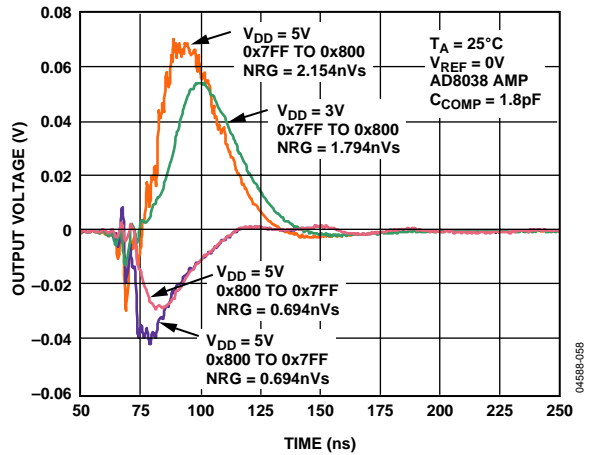


Figure 22. Midscale Transition,  $V_{REF} = 0\text{ V}$

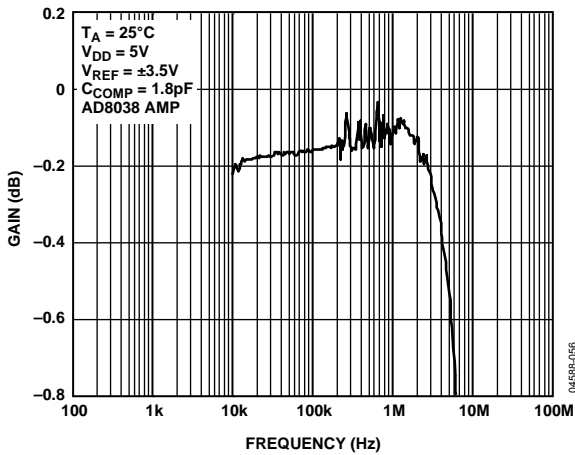


Figure 20. Reference Multiplying Bandwidth—All 1s Loaded

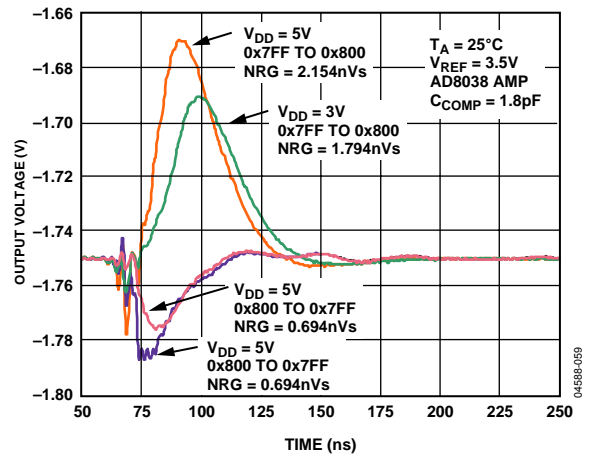


Figure 23. Midscale Transition,  $V_{REF} = 3.5\text{ V}$

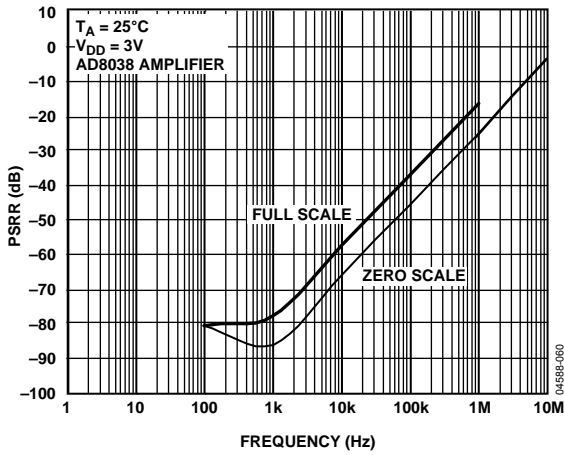


Figure 24. Power-Supply Rejection vs. Frequency

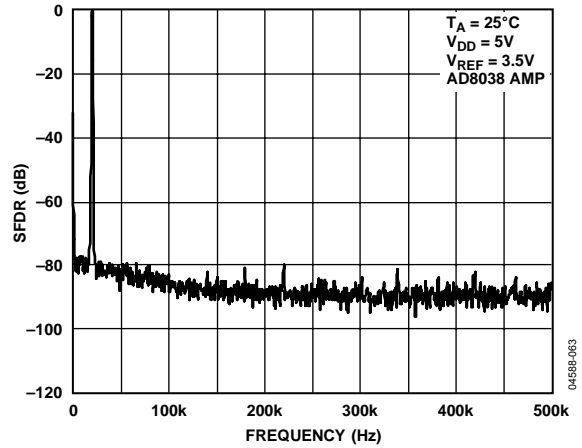


Figure 27. Wideband SFDR,  $f_{OUT} = 20$  kHz, Clock = 1 MHz

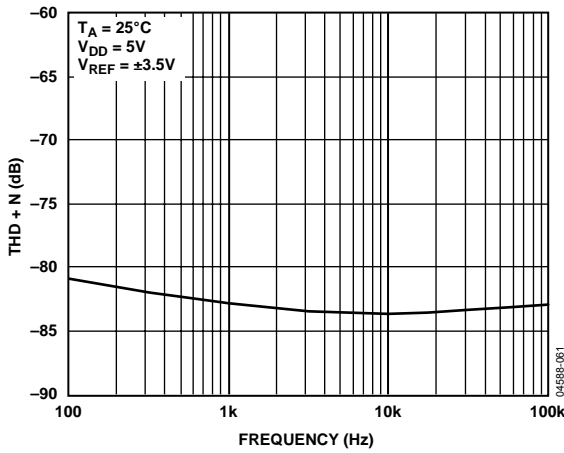


Figure 25. THD + Noise vs. Frequency

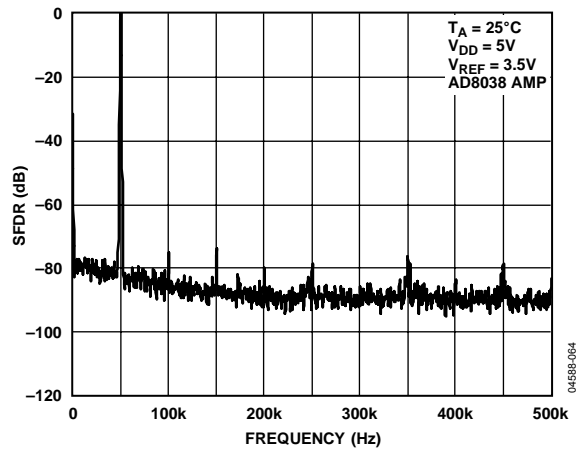


Figure 28. Wideband SFDR,  $f_{OUT} = 50$  kHz, Clock = 1 MHz

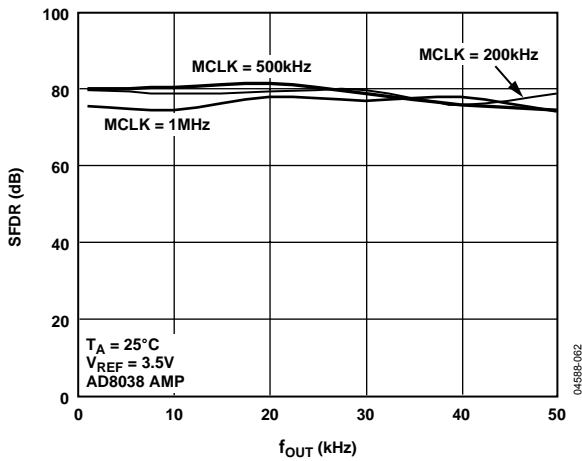


Figure 26. Wideband SFDR vs.  $f_{OUT}$  Frequency

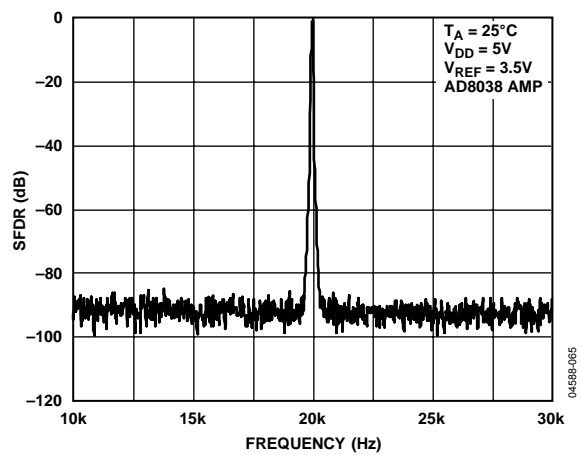


Figure 29. Narrow-Band SFDR,  $f_{OUT} = 20$  kHz, Clock = 1 MHz

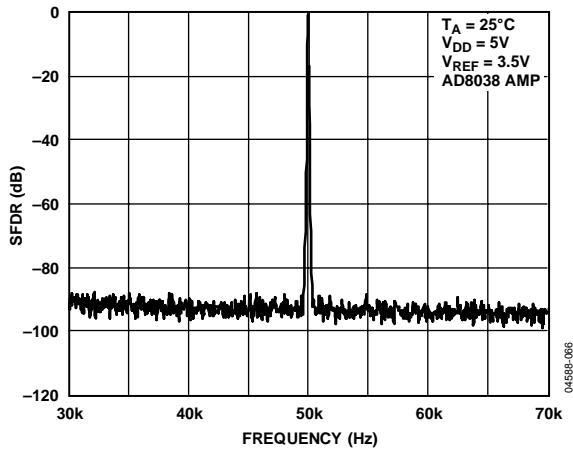


Figure 30. Narrow-Band SFDR,  $f_{OUT} = 50\text{ kHz}$ , Clock = 1 MHz

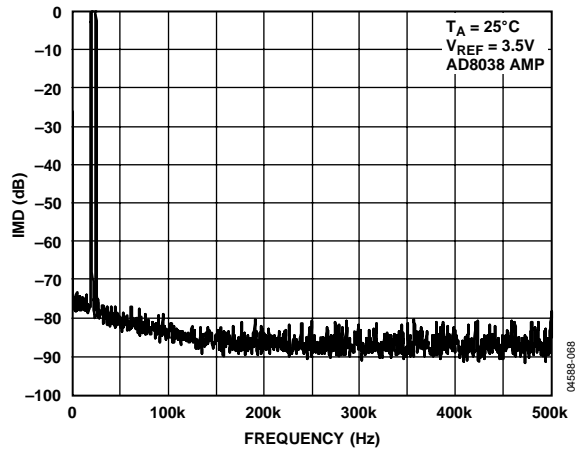


Figure 32. Wideband IMD,  $f_{OUT} = 20\text{ kHz}, 25\text{ kHz}$ , Clock = 1 MHz

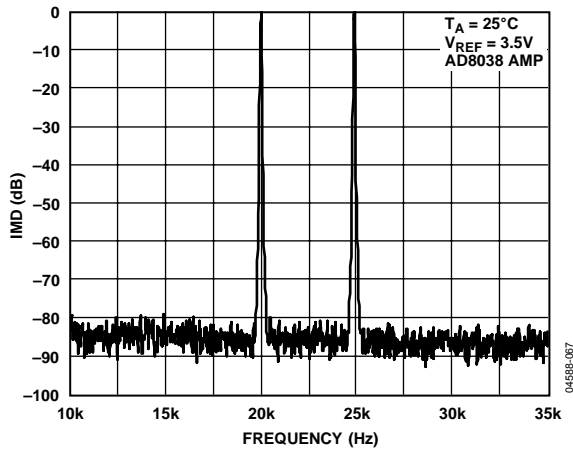


Figure 31. Narrow-Band IMD,  $f_{OUT} = 20\text{ kHz}, 25\text{ kHz}$ , Clock = 1 MHz

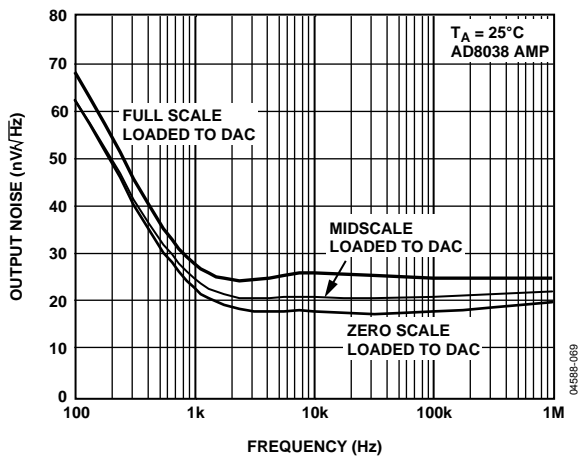


Figure 33. Output Noise Spectral Density

## GENERAL DESCRIPTION

### DAC SECTION

The AD5444 is a 12-bit current output DAC consisting of a segmented (4 bits) inverting R-2R ladder configuration. A simplified diagram for the 12-bit AD5444 is shown in Figure 34.

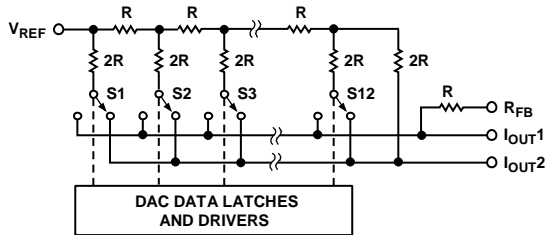


Figure 34. Simplified Ladder

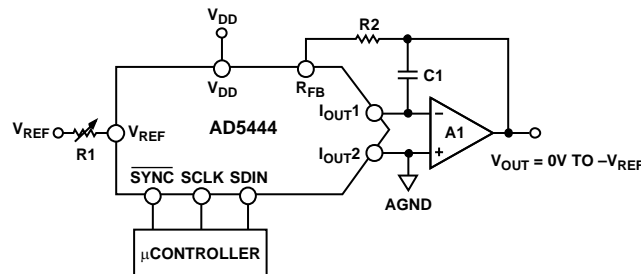
The feedback resistor  $R_{FB}$  has a value of  $R$ . The value of  $R$  is typically  $9\text{ k}\Omega$  ( $7\text{ k}\Omega$  minimum,  $11\text{ k}\Omega$  maximum). If  $I_{OUT1}$  is kept at the same potential as GND, a constant current flows in each ladder leg, regardless of digital input code. Therefore, the input resistance presented at  $V_{REF}$  is always constant and nominally of value  $R$ . The DAC output ( $I_{OUT}$ ) is code-dependent, producing various resistances and capacitances. The external amplifier choice should take into account the variation in impedance generated by the DAC on the amplifiers inverting input node.

Access is provided to the  $V_{REF}$ ,  $R_{FB}$ , and  $I_{OUT}$  terminals of the DAC, making the device extremely versatile and allowing it to be configured in several different operating modes, for example, to provide a unipolar output and in 4-quadrant multiplication in bipolar mode. Note that a matching switch is used in series with the internal  $R_{FB}$  feedback resistor. If users attempt to measure  $R_{FB}$ , power must be applied to  $V_{DD}$  to achieve continuity.

### CIRCUIT OPERATION

#### Unipolar Mode

Using a single op amp, these devices can easily be configured to provide 2-quadrant multiplying operation or a unipolar output voltage swing, as shown in Figure 35.



NOTES:  
<sup>1</sup>R1 AND R2 USED ONLY IF GAIN ADJUSTMENT IS REQUIRED.  
<sup>2</sup>C1 PHASE COMPENSATION (1pF TO 2pF) MAY BE REQUIRED, IF A1 IS A HIGH SPEED AMPLIFIER.

Figure 35. Unipolar Operation

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

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

where:

$D$  is the fractional representation of the digital word loaded to the DAC:

$$D = 0 \text{ to } 4095.$$

$$n \text{ is the number of bits.}$$

Note that the output voltage polarity is opposite to 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 used by the internal digital logic only to drive the DAC switches' on and off states. The 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 shown in Figure 35 gives an 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 Table

Digital Input	Analog Output (V)
1111 1111 1111	$-V_{REF} (4095/4096)$
1000 0000 0000	$-V_{REF} (2048/4096) = -V_{REF}/2$
0000 0000 0001	$-V_{REF} (1/4096)$
0000 0000 0000	$-V_{REF} (0/4096) = 0$

### Bipolar Operation

In some applications, it might be necessary to generate a full 4-quadrant multiplying operation or a bipolar output swing. This can be easily accomplished by using another external amplifier and some external resistors, as shown in Figure 36. In this circuit, the second amplifier, A2, provides a gain of 2. Biasing the external amplifier with an offset from the reference voltage results in a full 4-quadrant multiplying operation. The transfer function of this circuit shows that both negative and positive output voltages are created as the input data ( $D$ ) is incremented from code zero ( $V_{OUT} = -V_{REF}$ ) to midscale ( $V_{OUT} = 0$  V) to full scale ( $V_{OUT} = +V_{REF}$ ).

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

where:

$D$  is the fractional representation of the digital word loaded to the DAC:

$$D = 0 \text{ to } 4095.$$

$n$  is the resolution of the DAC.

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 Table

Digital Input	Analog Output (V)
1111 1111 1111	+V <sub>REF</sub> (2047/2048)
1000 0000 0000	0
0000 0000 0001	-V <sub>REF</sub> (2047/2048)
0000 0000 0000	-V <sub>REF</sub> (0/2048)

### Stability

In the I-to-V configuration, the  $I_{OUT}$  of the DAC and the inverting node of the op amp must be connected as closely as possible, and proper PCB layout techniques must be employed. Because every code change corresponds to a step function, gain peaking might occur if the op amp has limited GBP and excessive parasitic capacitance exists at the inverting node. This parasitic capacitance introduces a pole into the open-loop response that can cause ringing or instability in the closed-loop applications circuit.

An optional compensation capacitor, C1, can be added in parallel with  $R_{FB}$  for stability, as shown in Figure 35 and Figure 36. Too small a value for C1 can produce ringing at the output, while too large a value can adversely affect the settling time. C1 should be found empirically, but 1 pF to 2 pF is generally adequate for the compensation.

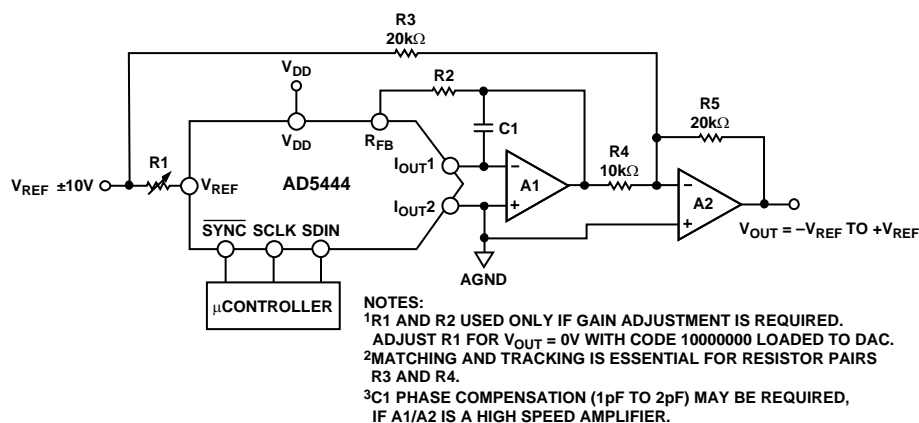


Figure 36. Bipolar Operation (4-Quadrant Multiplication)

## SINGLE-SUPPLY APPLICATIONS

### Voltage Switching Mode of Operation

Figure 37 shows the AD5444 DAC operating in the voltage-switching mode. The reference voltage,  $V_{IN}$ , is applied to the  $I_{OUT1}$  pin,  $I_{OUT2}$  is connected to AGND, and the output voltage is available at the  $V_{REF}$  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 op amp is necessary to buffer the output voltage. The reference input no longer sees a constant input impedance, but one that varies with code, so the voltage input should be driven from a low impedance source.

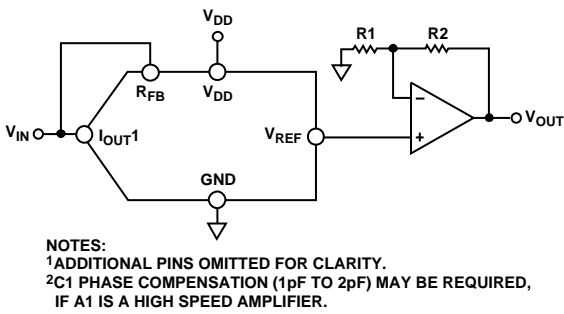


Figure 37. Single-Supply Voltage Switching Mode Operation

It is important to note that, with this configuration,  $V_{IN}$  is limited to low voltages, because the switches in the DAC ladder do not have the same source-drain drive voltage. As a result, their on resistance differs, which 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, exceeding the maximum ratings of the device. In this type of application, the full range of multiplying capability of the DAC is lost.

### Positive Output Voltage

The output voltage polarity is opposite to the  $V_{REF}$  polarity for dc reference voltages. To achieve a positive voltage output, an applied negative reference to the input of the DAC is preferred over the output inversion through an inverting amplifier because of the resistor's tolerance errors. To generate a negative reference, the reference can be level-shifted by an op amp such that the  $V_{OUT}$  and GND pins of the reference become the virtual ground and  $-2.5$  V, respectively, as shown in Figure 38.

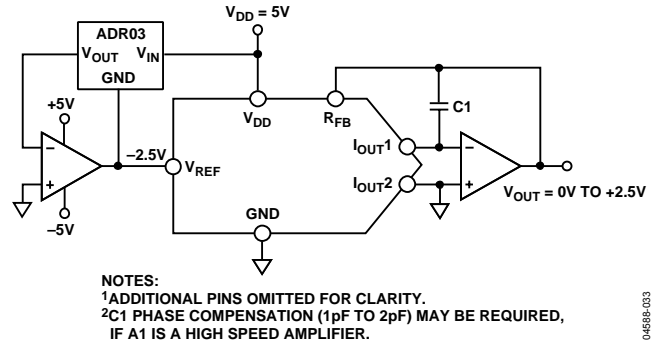


Figure 38. Positive Voltage Output with Minimum Components

## ADDING GAIN

In applications in which the output voltage is required to be greater than  $V_{IN}$ , gain can be added with an additional external amplifier, or it can be achieved in a single stage. It is important to take into consideration the effect of the temperature coefficients of the DAC's thin film resistors. Simply placing a resistor in series with the  $R_{FB}$  resistor can cause mismatches in the temperature coefficients and result in larger gain temperature coefficient errors. Instead, increase the gain of the circuit by using the recommended configuration shown in Figure 39.  $R_1$ ,  $R_2$ , and  $R_3$  should all have similar temperature coefficients, but they need not match the temperature coefficients of the DAC. This approach is recommended in circuits where gains of greater than 1 are required.

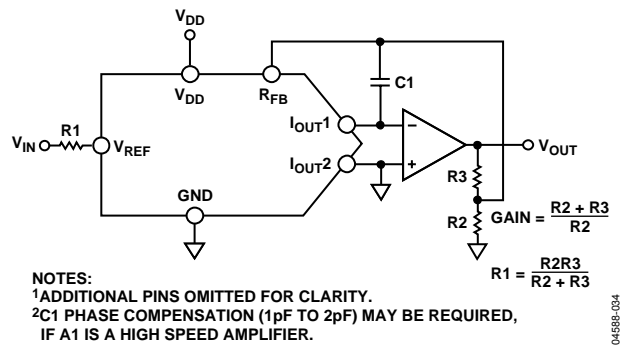


Figure 39. Increasing Gain of Current Output DAC

## DIVIDER OR PROGRAMMABLE GAIN ELEMENT

Current-steering DACs are very flexible and lend themselves to many different applications. If this type of DAC is connected as the feedback element of an op amp and  $R_{FB}$  is used as the input resistor, as shown in Figure 40, then the output voltage is inversely proportional to the digital input fraction,  $D$ .

For  $D = 1 - 2^{-n}$ , the output voltage is

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



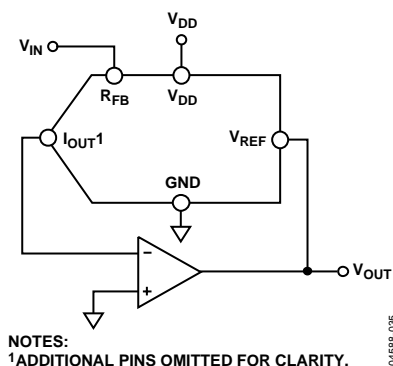


Figure 40. Current-Steering DAC Used as a Divider or Programmable Gain Element

As  $D$  is reduced, the output voltage increases. For small values of the digital fraction,  $D$ , it is important to ensure that the amplifier does not saturate and that 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 40 should cause the output voltage to be  $16 \times V_{IN}$ . However, if the DAC has a linearity specification of  $\pm 0.5$  LSB, then  $D$  can, in fact, have a weight in the range of  $15.5/256$  to  $16.5/256$ , so that the possible output voltage is in the range  $15.5 V_{IN}$  to  $16.5 V_{IN}$ . This is an error of 3%, even though the DAC itself has a maximum error of 0.2%.

DAC leakage current is also a potential error source in divider circuits. The leakage current must be counterbalanced by an opposite current supplied from the op amp through the DAC. Because only a fraction,  $D$ , of the current into the  $V_{REF}$  terminal is routed to the  $I_{OUT1}$  terminal, the output voltage has to change, as follows:

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

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

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

## AMPLIFIER SELECTION

The primary requirement for the current-steering mode is an amplifier with low input bias currents and low input offset voltage. The input offset voltage of an op amp is multiplied by the variable gain (due to the code-dependent output resistance of the DAC) 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's input offset voltage. This output voltage change is superimposed upon the desired change in output between the two codes and gives rise to a differential

linearity error, which, if large enough, could cause the DAC to be nonmonotonic.

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

Common-mode rejection of the op amp is important in voltage switching circuits, because it produces a code-dependent error at the voltage output of the circuit. Most op amps have adequate common-mode rejection for use at 8-bit, 10-bit, and 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 determined largely by the output op amp. To obtain minimum settling time in this configuration, it is important to minimize capacitance at the  $V_{REF}$  node (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. A large range of single-supply amplifiers is available from Analog Devices.

## REFERENCE SELECTION

When selecting a reference for use with the AD5444 current output DAC, pay attention to the reference's output voltage temperature coefficient specification. This parameter affects not only the full-scale error, but can also affect the linearity (INL and DNL) performance. The reference temperature coefficient should be consistent with the system accuracy specifications. For example, an 8-bit system required to hold its overall specification to within 1 LSB over the temperature range  $0^{\circ}\text{C}$  to  $50^{\circ}\text{C}$  dictates that the maximum system drift with temperature should be less than 78 ppm/ $^{\circ}\text{C}$ .

A 12-bit system with the same temperature range to overall specification within 2 LSBs requires a maximum drift of 10 ppm/ $^{\circ}\text{C}$ . By choosing a precision reference with low output temperature coefficient, this error source can be minimized. Table 7 suggests some of the dc references available from Analog Devices that are suitable for use with this range of current output DACs.

# AD5444

Table 7. Suitable ADI Precision References

Reference	Output Voltage (V)	Initial Tolerance (%)	Temperature Drift (ppm/°C)	0.1 Hz to 10 Hz Noise (μV p-p)	Package
ADR01	10	0.1	3	20	SC70, TSOT, SOIC
ADR02	5	0.1	3	10	SC70, TSOT, SOIC
ADR03	2.5	0.2	3	10	SC70, TSOT, SOIC
ADR425	5	0.04	3	3.4	MSOP, SOIC

Table 8. Suitable ADI Precision Op Amps

Part No.	Max Supply Voltage (V)	Max $V_{OS}$ (μV)	Max $I_B$ (nA)	GBP (MHz)	Slew Rate (V/μs)
OP97	±20	25	0.1	0.9	0.2
OP1177	±18	60	2	1.3	0.7
AD8551	6	5	0.05	1.5	0.4

Table 9. Suitable ADI High Speed Op Amps

Part No.	Max Supply Voltage (V)	Max $V_{OS}$ (μV)	Max $I_B$ (nA)	BW @ $A_{CL}$ (MHz)	Slew Rate (V/μs)
AD8065	±12	1500	0.01	145	180
AD8021	±12	1000	1000	200	100
AD8038	±5	3000	0.75	350	425
AD9631	±5	10000	7000	320	1300

## SERIAL INTERFACE

The AD5444 has an easy-to-use 3-wire interface that is compatible with SPI, QSPI, MICROWIRE, and DSP interface standards. Data is written to the device in 16-bit words. This 16-bit word consists of two control bits and 12 data bits, as shown in Figure 41. The AD5444 uses 12 bits and ignores the 2 LSBs.

### DAC Control Bits C1, C0

Control Bits C1 and C0 allow the user to load and update the new DAC code and to change the active clock edge. By default, the shift register clocks data on the falling edge, but this can be changed via the control bits. If changed, the DAC core is inoperative until the next data frame. A power cycle resets this back to the default condition. On-chip power-on reset circuitry ensures that the device powers on with zero scale loaded to the DAC register and I<sub>OUT</sub> line.

**Table 10. DAC Control Bits**

C1	C0	Function Implemented
0	0	Load and update (power-on default)
0	1	Disable SDO
1	0	No operation
1	1	Clock data to shift register on rising edge

### SYNC Function

SYNC is an edge-triggered input that acts as a frame synchronization signal. Data can be transferred into the device only while SYNC is low. To start the serial data transfer, SYNC should be taken low, observing the minimum SYNC falling to SCLK falling edge setup time,  $t_4$ . To minimize the power consumption of the device, the interface powers up fully only 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.

After the falling edge of the 16th SCLK pulse, bring SYNC high to transfer data from the input shift register to the DAC register.

### Daisy-Chain Mode

Daisy-chain mode is the default power-on mode. To disable the daisy-chain function, write 01 to the control word. In daisy-chain mode, the internal gating on the SCLK is disabled. The 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 the SCLK (this is the default; use the control word to change the active edge) and is valid for the next device on the falling edge (default). By connecting this line to the SDIN input on the next device in the chain, a multidevice interface is constructed. 16 clock pulses are required for each device in the system. Therefore, the total number of clock cycles must equal  $16N$ , where  $N$  is the number of devices in the chain.

When the serial transfer to all devices is complete, SYNC should be taken high. This prevents any further data from being clocked into the shift register. A burst clock containing the exact number of clock cycles can be used, and SYNC taken high some time later. After the rising edge of SYNC, data is automatically transferred from each device's input register to the addressed DAC.

When the control bits = 10, the device is in no operation mode. This can be useful in daisy-chain applications where the user does not want to change the settings of a particular DAC in the chain. Simply write 10 to the control bits for that DAC, and the following data bits are ignored.

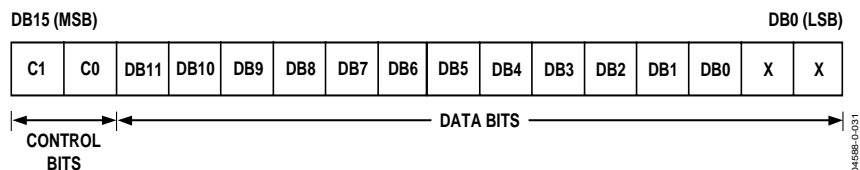


Figure 41. AD5444 12-Bit Input Shift Register Contents

# AD5444

## MICROPROCESSOR INTERFACING

Microprocessor interfacing to the AD5444 DAC is through a serial bus that uses standard protocol compatible with micro-controllers and DSP processors. The communications channel is a 3-wire interface consisting of a clock signal, a data signal, and a synchronization signal. The AD5444 requires a 16-bit word, with the default being data valid on the falling edge of SCLK, but this is changeable using the control bits in the data-word.

### ADSP-21xx to AD5444 Interface

The ADSP-21xx family of DSPs is easily interfaced to the AD5444 DAC without the need for extra glue logic. Figure 42 is an example of an SPI interface between the DAC and the ADSP-2191M. SCK of the DSP drives the serial data line, DIN. SYNC is driven from one of the port lines, in this case SPIxSEL.

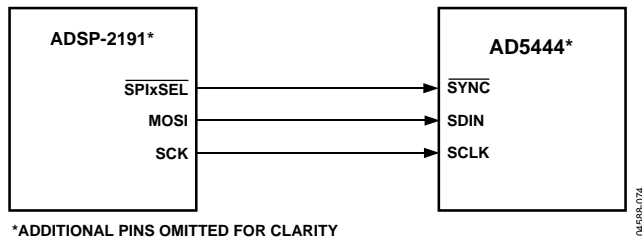


Figure 42. ADSP-2191 SPI to AD5444 Interface

A serial interface between the DAC and DSP SPORT is shown in Figure 43. 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 the SPORT has been enabled. In a write sequence, data is clocked out on each rising edge of the DSP's serial clock and clocked into the DAC input shift register on the falling edge of its SCLK. The update of the DAC output takes place on the rising edge of the SYNC signal.

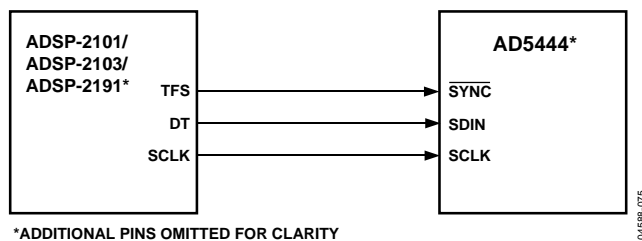


Figure 43. ADSP-2101/ADSP-2103/ADSP-2191 SPORT to AD5444 Interface

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  $t_1$  (SYNC falling edge to SCLK falling edge setup time) of 13 ns minimum. See the ADSP-21xx User Manual for information on clock and frame sync frequencies for the SPORT register.

Table 11 shows the setup for the SPORT control register.

Table 11. 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-BF5xx-to-AD5444 Interface

The ADSP-BF5xx family of processors has an SPI-compatible port that enables the processor to communicate with SPI-compatible devices. A serial interface between the ADSP-BF5xx and the AD5444 DAC is shown in Figure 44. In this configuration, data is transferred through the MOSI (master output/slave input) pin. SYNC is driven by the SPI chip select pin, which is a reconfigured programmable flag pin.

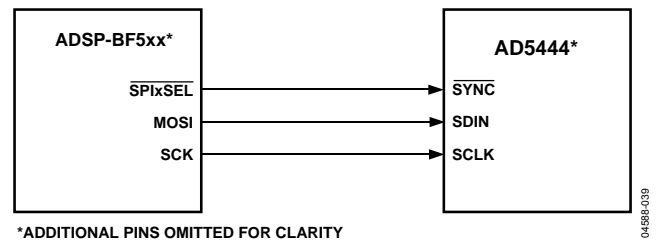


Figure 44. ADSP-BF5xx-to-AD5444 Interface

The ADSP-BF5xx processor incorporates channel synchronous serial ports (SPORT). A serial interface between the DAC and the DSP SPORT is shown in Figure 46. When the 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's serial clock and clocked into the DAC's input shift register on the falling edge of its SCLK. The DAC output is updated by using the transmit frame synchronization (TFS) line to provide a SYNC signal.

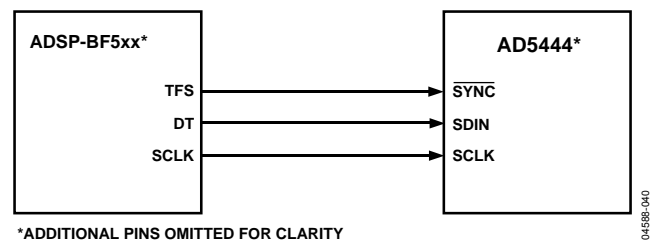


Figure 45. ADSP-BF5xx to AD5444 Interface

### 80C51/80L51 to AD544 Interface

A serial interface between the DAC and the 80C51/80L51 is shown in Figure 46. TxD of the 80C51/80L51 drives SCLK of the DAC serial interface, while RxD drives the serial data line, SDIN. P1.1 is a bit-programmable pin on the serial port and is used to drive  $\overline{\text{SYNC}}$ . When data is to be transmitted to the switch, P1.1 is taken low. The 80C51/80L51 transmits data only 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. 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 80C51/80L51 provides the LSB of its SBUF register as the first bit in the data stream. The DAC input register requires its data with the MSB as the first bit received. The transmit routine should take this into account.

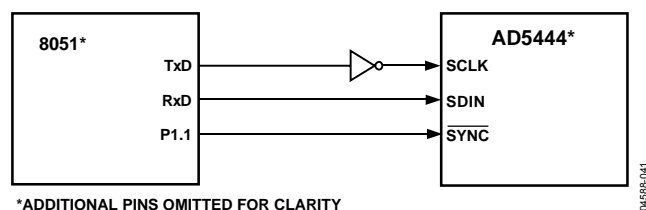


Figure 46. 80C51/80L51 to AD5444 Interface

### MC68HC11 Interface to AD5444 Interface

Figure 47 is an example of a serial interface between the DAC and the MC68HC11 microcontroller. 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 AD5444.

The  $\overline{\text{SYNC}}$  signal is derived from a port line (PC7). When data is being transmitted to the AD5444, the  $\overline{\text{SYNC}}$  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, PC7 is left low after the first eight bits are transferred, and a second serial write operation is performed to the DAC. PC7 is taken high at the end of this procedure.

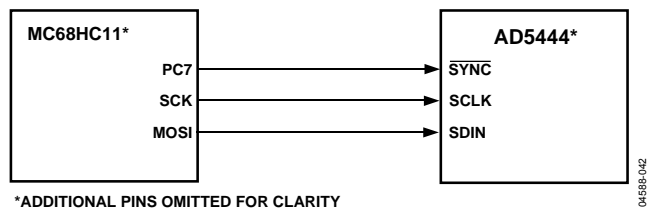


Figure 47. 68HC11/68L11 to AD5444 Interface

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  $\overline{\text{SYNC}}$  low, the shift register clocks data out on the rising edges of SCLK.

### MICROWIRE to AD5444 Interface

Figure 48 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's SCLK.

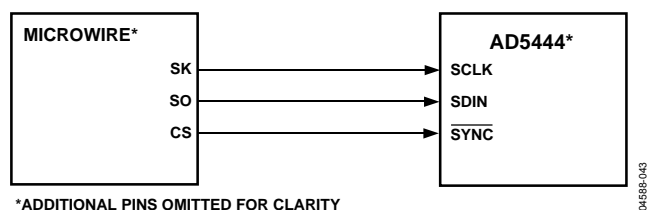


Figure 48. MICROWIRE to AD5444 Interface

### PIC16C6x/7x to AD5444 Interface

The PIC16C6x/7x 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); see the *PIC16/17 Microcontroller User Manual*.

In this example, I/O port RA1 is used to provide a  $\overline{\text{SYNC}}$  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 49 shows the connection diagram.

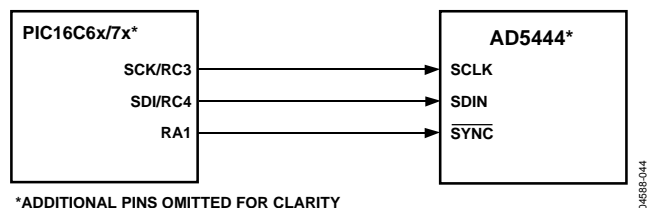


Figure 49. PIC16C6x/7x to AD5444 Interface

## PCB LAYOUT AND POWER SUPPLY DECOUPLING

In any circuit where accuracy is important, careful consideration of the power supply and ground return layout helps to ensure the rated performance. The printed circuit boards on which the AD5444 are mounted should be designed so that the analog and digital sections are separated and confined to certain areas of the board. If the DACs are in systems in which multiple devices require an AGND-to-DGND connection, the connection should be made at one point only. The star ground point should be established as close as possible to the devices.

The DAC should have ample supply bypassing of 10  $\mu\text{F}$  in parallel with 0.1  $\mu\text{F}$  on the supply located as close to the package as possible, ideally right up against the device. The 0.1  $\mu\text{F}$  capacitor should have low effective series resistance (ESR) and effective series inductance (ESI), like the common ceramic types 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 should also be applied at the supplies to minimize transient disturbance and filter out low frequency ripple.

Fast-switching signals such as clocks should be shielded with digital ground to avoid radiating noise to other parts of the board, and should never be run near the reference inputs.

Avoid crossover of digital and analog signals. Traces on opposite sides of the board should run at right angles to each other. This reduces the effects of feedthrough through the board. A microstrip technique is by far the best, but not always possible with a

double-sided board. In this technique, the component side of the board is dedicated to the ground plane, while signal traces are placed on the solder side.

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

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

### EVALUATION BOARD FOR THE DAC

The evaluation board consists of an AD5444 DAC and a current-to-voltage amplifier, AD8065. Included on the evaluation board is a 10 V reference, ADR01. An external reference can also be applied via an SMB input.

The evaluation kit consists of a CD-ROM with self-installing PC software to control the DAC. The software allows the user to write a code to the device.

### POWER SUPPLIES FOR THE EVALUATION BOARD

The board requires  $\pm 12\text{ V}$  and  $+5\text{ V}$  supplies. The 12 V  $V_{\text{DD}}$  and  $V_{\text{SS}}$  are used to power the output amplifier, while the 5 V supply is used to power the DAC ( $V_{\text{DD1}}$ ) and transceivers ( $V_{\text{CC}}$ ).

Both supplies are decoupled to their respective ground plane with 10  $\mu\text{F}$  tantalum and 0.1  $\mu\text{F}$  ceramic capacitors.

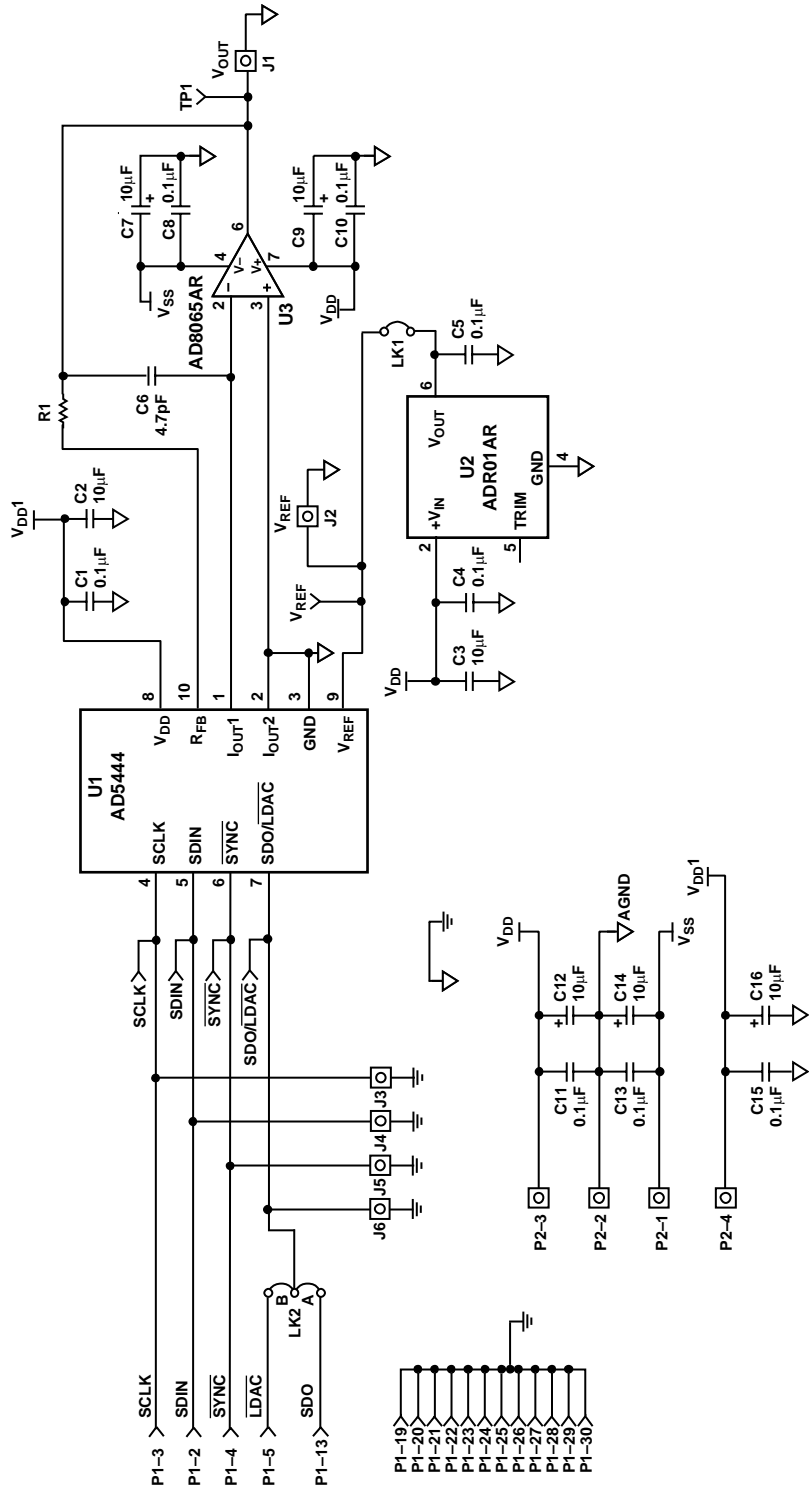


Figure 50. Schematic of the AD5444 Evaluation Board

045588-070

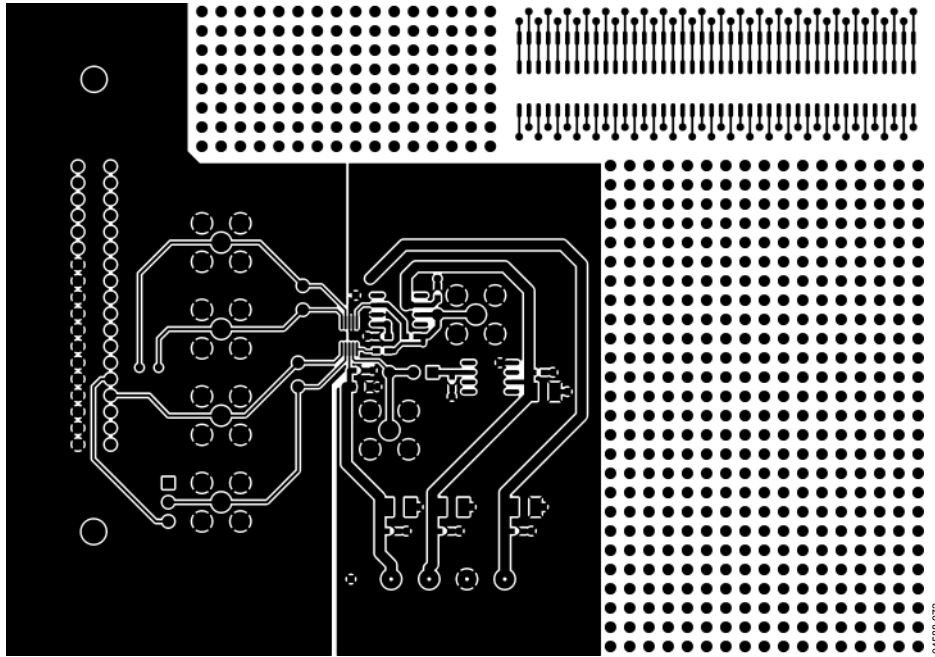


Figure 51. Component-Side Artwork

04588-072

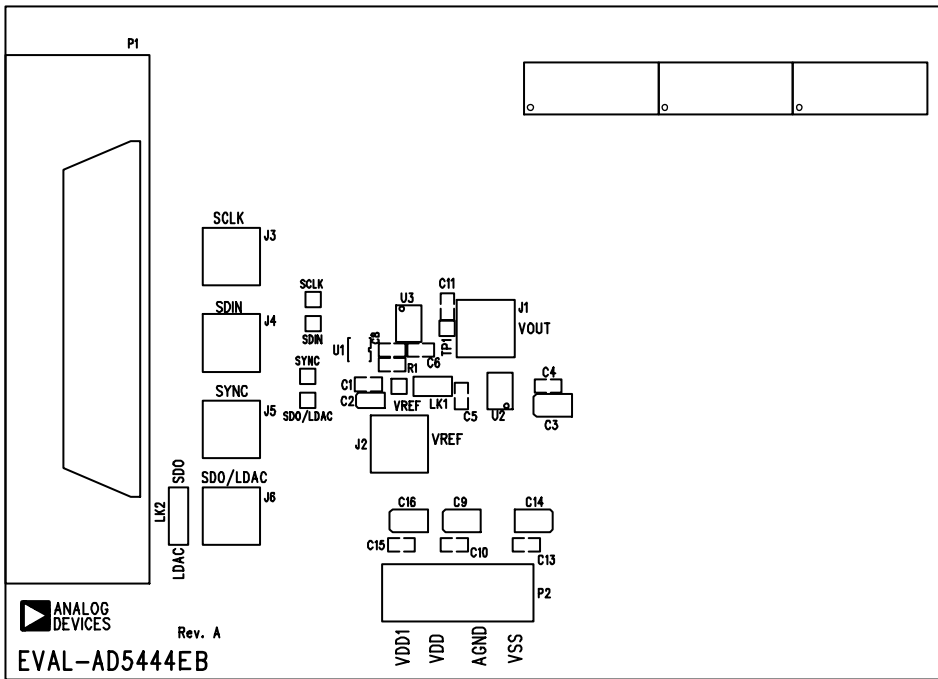


Figure 52. Silkscreen—Component-Side Artwork (Top)

04588-071



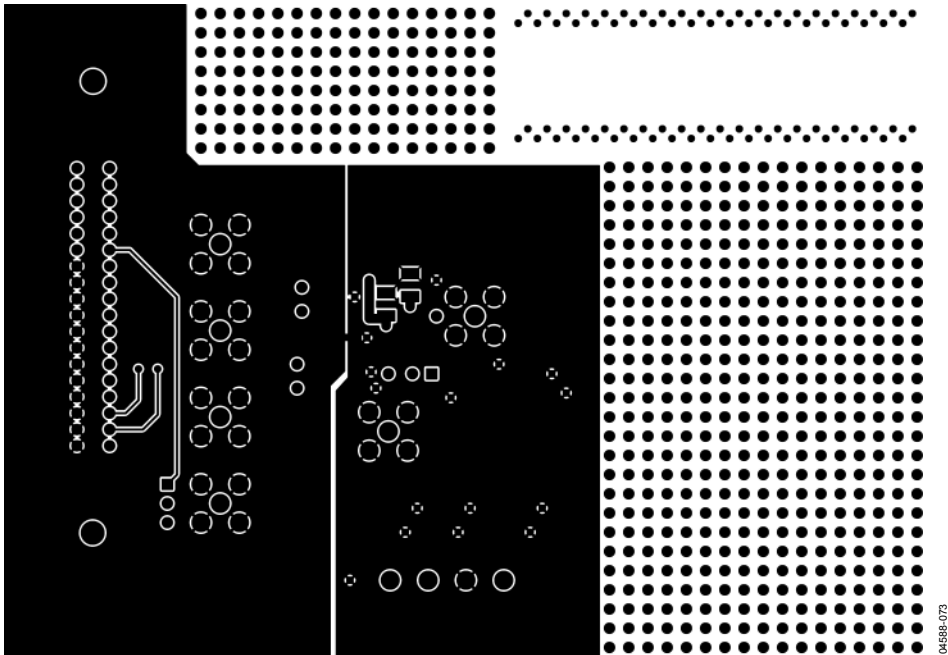


Figure 53. Solder-Side Artwork

## OVERVIEW OF AD54XX DEVICES

Table 12.

Part No.	Resolution	No. DACs	INL(LSB)	Interface	Package	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	RJ-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	RJ-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	50 MHz Serial Interface
AD5415	12	2	±1	Serial	RU-24	10 MHz BW, 58 MHz Serial
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	RJ-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

## OUTLINE DIMENSIONS

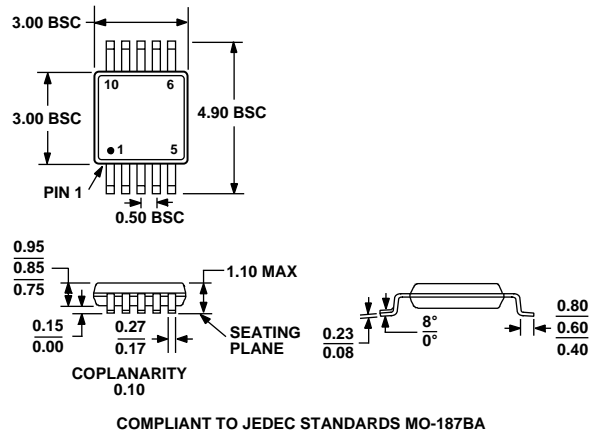


Figure 54. 10-Lead Mini Small Outline Package [MSOP] (RM-10)  
Dimensions shown in millimeters

## ORDERING GUIDE

Model	Resolution	INL	Temperature Range	Package Description	Package Option	Branding
AD5444YRM	12	±0.5	-40°C to +125°C	MSOP	RM-10	D27
AD5444YRM-REEL	12	±0.5	-40°C to +125°C	MSOP	RM-10	D27
AD5444YRM-REEL7	12	±0.5	-40°C to +125°C	MSOP	RM-10	D27
EVAL-AD5444EB				Evaluation Board		

**AD5444**

**NOTES**